U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-109978

Guidelines to Air Quality Management Systems

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

Apr 79

PB80-109978

COMMITTEE ON
THE CHALLENGES OF
MODERN SOCIETY

AIR QUALITY MANAGEMENT SYSTEMS (Revised)

Number 71

NORTH ATLANTIC TREATY ORGANIZATION

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. NATO/CCMS . 71	2.	3. RECIPIENT'S ACCESSION NO. PB 80 109978
4. TITLE AND SUBTITLE Air Quality Management Systems (Revised)		5. REPORT DATE April 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS A report by the NATO/CCMS Pilot Study on Air Pollution Assessment Methodology and Modelling.		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS North Atlantic Treaty Organization Committee on the Challenges of Modern Society		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report describes Air Quality Management Systems and their technical and economical requirements and their legal and administrative implications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES 167
	20. SECURITY CLASS *(This page)*	22. PRICE A08-A01

EPA Form 2220-1 (9-73)

GUIDELINES TO
AIR QUALITY MANAGEMENT SYSTEMS

A Report by the NATO/CCMS

Pilot Study on Air Pollution Assessment
Methodology and Modeling

N. 71 (revised)

COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY
NORTH ATLANTIC TREATY ORGANISATION
APRIL 1979

Preface

The North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society" (CCMS) at the November 1969 meeting of the North Atlantic Council.

The CCMS was charged with developing meaningful environmental and social programs that complement other international programs, and with showing leadership, first, in solution of existing problems and, second, in development of long-range goals for environmental protection in the NATO sphere of influence and in other countries as well. A first Pilot Study on Air Pollution was initiated by the CCMS at its inaugural meeting in December 1969. The United States (Environmental Protection Agency) has been the pilot nation with the Federal Republic of Germany (Federal Ministry of the Interior) and Turkey (Scientific and Technical Research Council) as copilot-nations.

The Pilot Study on Air Pollution was an action program designed to demonstrate and encourage the utilization of existing knowledge for the development of air quality management programs. It entailed the demonstration of a systems approach to air quality management. Case studies have been carried out in Ankara, Turkey; Frankfurt, Federal Republic of Germany; St. Louis, U. S.; Oslo, Norway; South Holland Region, The Netherlands (NATO/CCMS Report No. 6, Appendices A - E).

The results of the pilot study are documented in NATO/CCMS Report No. 6 (Revised) "Guidelines to Assessment of Air Quality" of October 1972 and in NATO/CCMS Report No. 33 (Final Report) containing 15 recommendations as well as in several other documents, listed as Annex II to this document.

Starting from three of the above recommendations (VI, VII and XIV) the Federal Republic of Germany proposed to initiate a new Pilot Study on Air Pollution Assessment Methodology and Modeling at the CCMS Plenary Session on October 22 and 23, 1974.

These NATO/CCMS Recommendations are:

RECOMMENDATION VI

Member nations will co-operate to develop standardized methods for emissions data storage and retrieval to support requirements in the conduct of national air quality management programs. The US National Emission Data System (NEDS) might serve as a model for a common international system.

RECOMMENDATION VII

Member nations will co-operate to develop standardized techniques for projecting emissions and predicting future ambient air quality.

RECOMMENDATION XIV

Member nations agree the CCMS modeling activity has shown that there is a widespread need for further international co-operation to accomplish the following tasks:

> Bring together model developers and air quality managers for exchange of ideas, discussion of users' needs and demonstration of modeling techniques.

Standardize modeling techniques for specific air quality management applications and consider how computerized models might be made available for all users.

Continue to review on-going air quality assessment studies.

In spring 1975 the North Atlantic Council approved the German proposal. The pilot study work started with the Federal Republic of Germany (Federal Ministry of the Interior) as pilot nation and the United States of America (Environmental Protection Agency) and Belgium (Service du Premier Ministre) as co-pilot nations:
A Working Group and two Panels were established with the following functions:

Assessment Methodology Panel

- Pursue and carry out Recommendations VI and VII
- Continue to review present and future assessment studies with respect to the application of assessment methodology.

Modeling Panel

- Develop standardized models for various air quality management applications.
- Develop programs to improve modeler/user communications in conjunction with the Assessment Methodology Panel and the Working Group.

- Continue as an information forum on new modeling concepts and techniques, organizing once a year international technical meetings on air pollution modeling and its application.

In addition the Working Group established an Ad-Hoc Group on Air Quality Management Systems to revise and update the NATO/CCMS Report No. 6 (Revised), 1972, by preparing a new document on "Guidelines to Air Quality Management Systems".

Another Ad-Hoc Group was set up for compiling a Glossary of Terms frequently used in assessment methodology, modeling and air quality management systems.

As an outcome of this Pilot Study on Air Pollution Assessment Methodology and Modeling the following NATO/CCMS documents are published (see also Annex III):

Air Quality Management Systems

- Guidelines to Air Quality Management Systems

Assessment Methodology

- Air Pollution Emissions Inventory Systems
- Air Pollution Emissions Projecting

Air Pollution Modeling

- Introduction to Air Quality Modeling
- Uses and Needs for Air Quality Modeling

- Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models)
- Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques)
- Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume)
- Fundamentals for the Applications of a Gaussian Plume Model

Other Publications

- Glossary of Terms
- Proceedings of the 6th to 9th International Technical Meetings on Air Pollution Modeling and its Application
  (6th Meeting, 24. - 26. Sept. 1975, Frankfurt/Main, Germany)
  (7th Meeting, 7. - 10. Sept. 1976, Airlie House, USA)
  (8th Meeting, 20. - 23. Sept. 1977, Louvain-la-Neuve, Belgium)
  (9th Meeting, 29. - 31. Aug. 1978, Toronto, Canada).

The chairman of the Working Group wishes to acknowledge the scientists participating from pilot, copilot, and observer countries, and the many other persons, who assisted in the preparation of this document.

The ad-hoc group on Air Quality Management Systems, which performed diligently throughout the course of this effort, receives the highest praise. The group consisted of the following members:

Federal Republic of Germany - Pilot Country

H. Meinl C. Morawa E. Weber

United States of America - Copilot Country

J. Bosch

Canada - Observer

M. Kwizak

The Netherlands - Observer

P. Gootjes	T. Schneider

United Kingdom - Observer

A. Keddie

The names and addresses of all panel members are listed in Annex I.

Full recognition is given to each member for carrying out and coordinating review and other activities related to the development of this document in his respective country, to Mr. T. Schneider for his chairmanship and to Ms. C. Morawa of the Federal Environmental Office, Germany for her effort in coordinating and organising the editorial work.

For the Working Group,
Erich Weber, Chairman.

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Appendix A Air Pollution Emissions Inventory Systems

Appendix B Air Pollution Emissions Projecting

Appendix C Introduction to Air Quality Modeling

1. INTRODUCTION

Air pollution problems have existed for centuries but only in the last century and a half, a period of explosive scientific and technological advances, have these problems become severe.

Man's activities have affected the natural air resource so severely in several areas of the globe, that strict measures of control and abatement are essential to prevent further threats to human health, animals, plants, ecosystems and materials. Meteorological and topographical conditions may add to and increase the undesirable resultant air quality effects. On the other hand, pollutants dispersed into the atmosphere exert both local and global scale influences on climate. Because of interregional and long range transmission in the atmosphere, some aspects of air pollution have become of global concern. Regional and world wide air pollution has been identified by many national and international monitoring programs.

There is abundant evidence that air pollution has adverse effects on man's health and well-being, on animals, plants and materials, on other environmental media and climate.

Despite efforts to reduce emissions of particular sources and pollutants, both the amount of air pollution and the number of different contaminating substances have increased, due to the growth of population and the industrialization. Additional and coordinated activities to control air pollution are a subject of immediate concern to the industrialized countries, but they should be of equal concern to other countries in the world.

It is therefore not sufficient to control air pollution by means of single isolated actions; control actions have to be integrated into a coordinated Air Quality Management System (AQMS). Several Air Quality Management Systems are possible depending on a variety of political, scientific and economic constraints. These constraints include the goals of a national air quality protection policy, the position of air quality protection within the priority scale of public interest, the legal basis, the state and the development of technology, the demographic and economic development. An AQMS, as described in this document, combines several elements with respect to legislation, implementation and control effectiveness.

An AQMS must address itself to the application of environmental assessment and control procedures to the vast discharges of pollutants into the environment. This effort has barely begun. Environmental legislation around the world is diverse and varied and includes mostly regulations dealing with separate permits for discharges into water, air and soil.

Land use and air quality can be expressed as observable facts. Planned land use and desired air quality are long-term objectives which need to be attained. Both are indispensable parts of a control strategy.

They are all the more important because our knowledge of the temporal and spatial relationship between emissions and their effects is incomplete. Temporal effects may be immediate or cumulative over long periods; spatial effects may vary from local impacts to effects over long distances.

A complete AQMS is expensive and requires considerable effort. An important aspect in this context is the relation between AQMS and employment. Beneficial and adverse effects on social and economic structural patterns will result (e.g. on population, migration, growth, product costs, public and private industry investment, etc.).

An AQMS can have a positive impact upon employment due to an increased demand for labour with various technological skills (e.g. for construction of air quality measurement instruments, telecommunications and data-processing systems, pollution abatement equipment, and manpower for government and industry control activities). In a relatively short period of time, the beneficial effects upon the social, economic and political aspects are expected to outweigh the initial adverse effects (e.g. monitoring costs, abatement equipment capital expenditures, reallocation of certain industries, etc.).

It should be noted that an AQMS is needed primarily in those regions where adverse effects caused by air pollution exist or are expected to occur in future.

This document is intended as a guideline for establishing systems to be used in the prevention of air pollution, to halt the degradation of air quality and in identifying possible interactions with other environmental media.

The guideline describes Air Quality Management Systems; it describes their building blocks as well as the technical and economical requirements and their legal and administrative implications in connection with ambient air quality standards and overall control strategies.

The guideline is addressed to national, regional and local authorities concerned with establishment and operation of an Air Quality Management System (AQMS), and it should be used by the manager of an AQMS or similar authorities.

In order to appreciate all aspects of the AQMS the reader is advised to run through the whole guideline book and not to start reading single chapters. Only after having an overall impression one should decide which chapters are of major importance for a specific application.

2. DESCRIPTION OF AIR QUALITY MANAGEMENT SYSTEMS (AQMS)

An AQMS is the consistent assembly of

- the assessment of present ambient air quality, emissions and related factors
- the comparison with existing standards, criteria and guidelines

- projection of future emissions and ambient air quality
- the development, implementation, and revision of a control strategy including economic aspects and interactions with other environmental media.

It aims to attain and maintain an acceptable level of ambient air quality. Although emphasis is mostly placed upon human health effects, it includes all ecosystems to obtain an approach covering the whole of the environment.

The AQMS comprises the past history, the present situation and future developments of air quality in the region concerned. In the AQMS the assembled information is used to develop a strategy plan. The plan is implemented, results are analysed and, if necessary, the plan is revised within the framework of the AQMS.

To attain this goal, an AQMS can use:

- emission standards (including design, construction and operating standards)
- equipment standards and product standards
- ambient air quality standards or objectives.

Appropriate combinations of emission standards, ambient air quality standards or objectives, product and equipment standards and other principles (e.g. stand-still) produce the most complete AQMS (Fig. 1).

Its characteristic elements are:

- Emission standards defined on the basis of the best available control technology, independent of ambient air quality. The same advanced technology has to be applied in polluted as well as in unpolluted areas.
- Ambient air quality standards or objectives, defined on the basis of the relationship between a pollutant´s dose, concentration, deposition rate or any other air quality related factor and the direct and/or indirect effects on receptors.
- Avoiding degradation of air quality in regions where pollution levels are below the ambient air quality standards (principle of non-degradation).
- Equipment standards and product standards as described in this guideline.
- Incorporation of air pollution aspects in all town and regional planning processes.

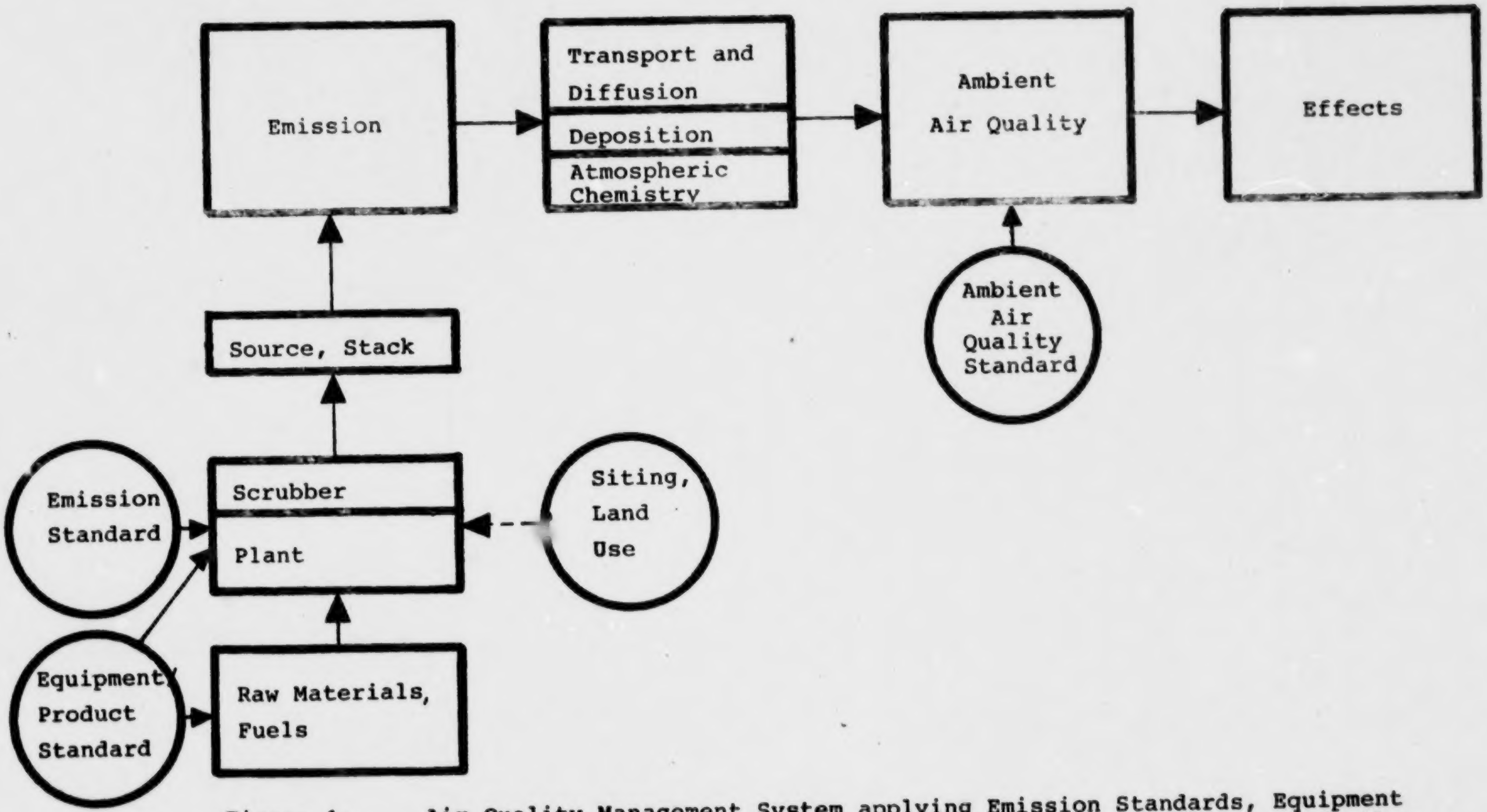
Emission
Transport and Diffusion
Deposition
Atmospheric Chemistry
Ambient Air Quality
Effects
Ambient Air Quality Standard
Source, Stack
Scrubber
Plant
Siting, Land Use
Emission Standard
Equipment, Product Standard
Raw Materials, Fuels

Figure 1: Air Quality Management System applying Emission Standards, Equipment Standards, Product Standards, Ambient Air Quality Standards ~~and other~~ suitable Measures

An AQMS using EMISSION STANDARDS limits the discharge of air pollutants from stationary and mobile sources expressed either in terms of concentrations or mass flow rates. Emission standards should be defined on the basis of the best available control technology (Fig. 2).

Best available control measures should take into account advanced technology, even if this technology has been successfully applied on a pilot scale only. Application of the best available control technology can easily be enforced in the case of new plants (e.g. by means of a licensing procedure). The set of regulations to achieve suitable emission reduction is generally developed in the assessment phase and integrated into the comprehensive strategy plan. Available control technology and sound measuring techniques are absolutely essential to the successful application of emission control regulations, yet surprisingly these requirements are often ignored in the haste to reduce emissions in a community. The first generation of emission control regulations often reflects inexperience, unrealistic time schedules, inadequate data bases, and a rather idealistic belief that the objectives will be achieved simply by having them written into a regulation. Despite these difficulties there is often a remarkable similarity of emission control laws in widely diverse regions probably due to the forced deadlines and a common need to accept advice from anyone with previous experience.

Initial efforts to reduce emissions invariably emphasize the control of existing sources and this approach is sometimes costly due to the retrofit of in-place processes and equipment already in place. As the AQMS evolves, the emphasis is shifted mostly towards preventing new emissions of pollutants through the use of emission standards. It should be recognized that the control of emissions from existing facilities usually involves compromise by both the responsible agency and the industrial facility. Thus, the final outcome is settled on a case-by-case basis and may differ significantly from the required reductions for a similar source in another area. Emission standards for new sources, on the other hand, do not have this disadvantage since they can be applied in advance and uniformly to all new sources employing a given process or producing a particular product.

Air pollution results from industrial plants as well as from the more numerous small sources, e.g. space heating devices and motor vehicles. It may therefore be necessary to set up emission standards for these source categories as well. It is extremely difficult to apply best available control technology to old heating installations or cars, consequently the use of emission standards may not be adequate.

Even if the concept of emission standards is applied, an agglomeration of industry, population and traffic, in combination with meteorological and topographical conditions, may still cause unacceptable levels of air pollution.

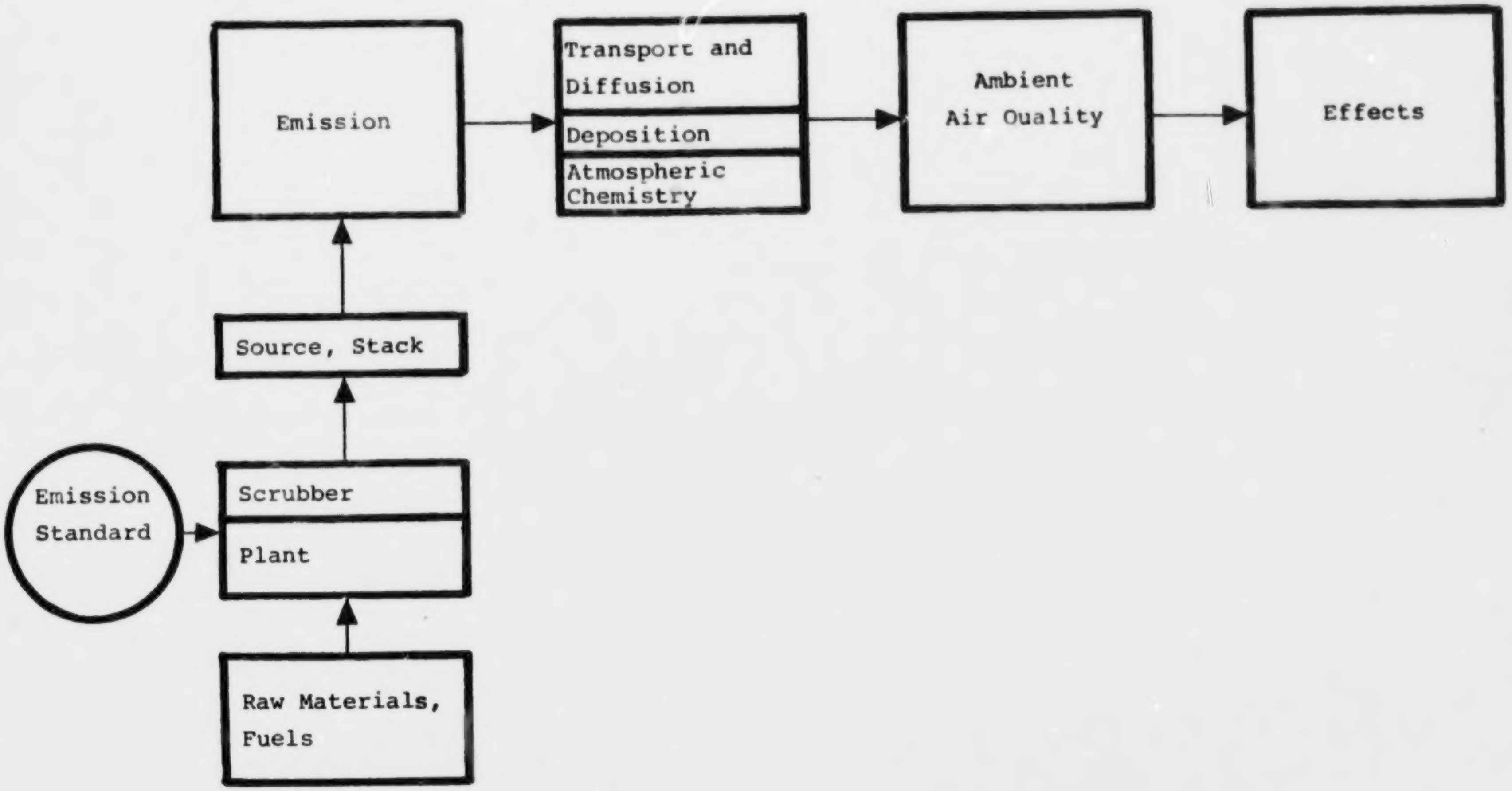
Emission
Transport and Diffusion
Deposition
Atmospheric Chemistry
Ambient Air Quality
Effects
Source, Stack
Emission Standard
Scrubber
Plant
Raw Materials, Fuels

Fig. 2: Air Quality Management System applying Emission Standards

Other means to reduce emissions are EQUIPMENT STANDARDS and PRODUCT STANDARDS (Fig. 3). Equipment standards specify design characteristics for equipments, product standards specify the composition of fuels, raw materials or products. Both types of standards are normally only applied to equipments or products used in large quantities.

Equipment standards and product standards may help to reduce emissions more generally than emission standards for single sources. For instance, a limitation of the sulfur content of coal or fuel oil will reduce SO_2-emission of all coal and oil burning facilities in a given country. Limitation of the lead content of gasoline will reduce the lead emission of all motor vehicles. Specifications for construction details of motor vehicles, e.g. the recycling of crankcase emissions, or absorbing emissions from gasoline tank pressurizing systems will reduce emissions of all cars.

To meet product standards, development of new processing techniques may sometimes be necessary; to produce fuel oil with low sulfur content, new desulfurization devices in refineries must be installed.

An appreciable reduction of air pollution by means of equipment standards or product standards may be reached if they are applied on a nationwide or international basis.

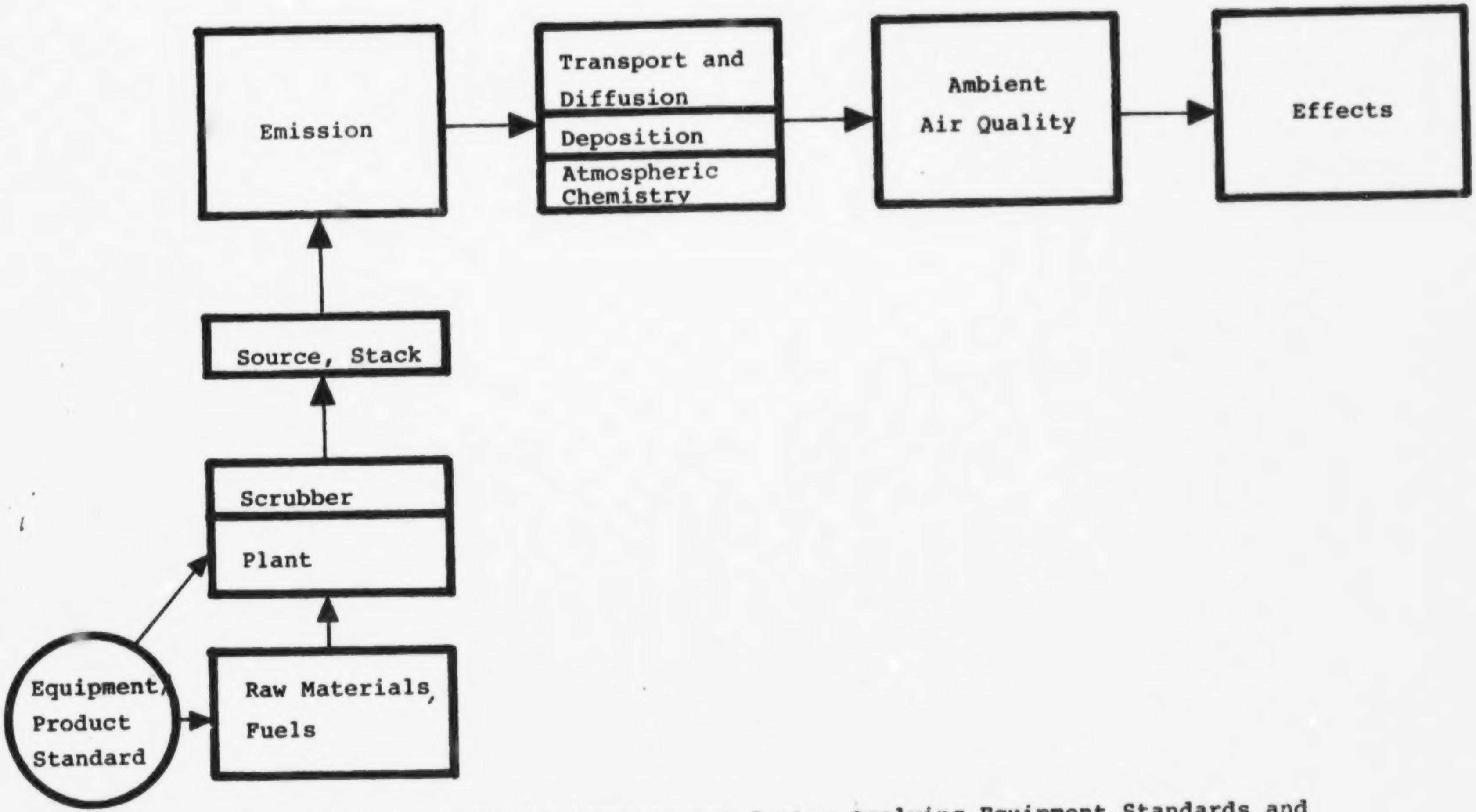
Emission
Transport and Diffusion
Deposition
Atmospheric Chemistry
Ambient Air Quality
Effects
Source, Stack
Scrubber
Plant
Raw Materials, Fuels
Equipment, Product Standard

Figure 3: Air Quality Management System applying Equipment Standards and Product Standards

While emission standards, equipment standards, and product standards affect sources and emissions directly, AIR QUALITY STANDARDS specify the level of ambient air quality which should be achieved (Fig. 4). These standards relate directly to measurable effects on health or welfare. Frequently these ambient air quality standards or criteria lead to further emission controls of specific sources. In the USA maximum allowable fluoride concentrations in animal forage have been successfuly used as a receptor/effect standard to trigger further emission controls in aluminium refining processes.

For the position of ambient air quality standards within an AQMS see Fig. 4. All measures affecting the total amount and the spatial and temporal distribution of emissions are related to this ambient air quality level.

Normally, this level is defined in terms of concentrations of air polluting substances which should not be exceeded during a specified time period in a specified area.

This desired level may

- be based on the relationship between the dose, concentration, deposition rate or any other air quality related factor of a pollutant and its direct and/or indirect effect on receptors,
- state that the present ambient air quality should not deteriorate (non-degradation principle),

- - in the absence of the above - state that ambient air quality should be as good as it has been x years ago,
- state that ambient air quality should be as good as it is in a certain other region.

If the desired level of ambient air quality is defined on a legal basis, it is called a standard, if not, it may be regarded as an objective.

The basic requirements of an AQMS based on ambient air quality standards or criteria are the following:

- existing ambient air quality and emissions have to be identified by means of an assessment program;
- future ambient air quality has to be projected by means of an air quality simulation model, using a projected emissions inventory together with all other relevant input parameters;
- existing and expected future ambient air quality has to be compared to standards or objectives;
- if the existing or the expected future ambient air quality exceeds the standards or objectives, a strategy plan must be set up.

The advantage of this approach is that it defines the objective of the management program on the basis of ambient air quality; all abatement measures are then designed to meet the objective.

The disadvantages are - if it is applied strictly on its own - that it may impose different emission abatement measures to the same sources in regions with different pollution levels and that it may cause a region to get saturated with pollution until the standard is reached.

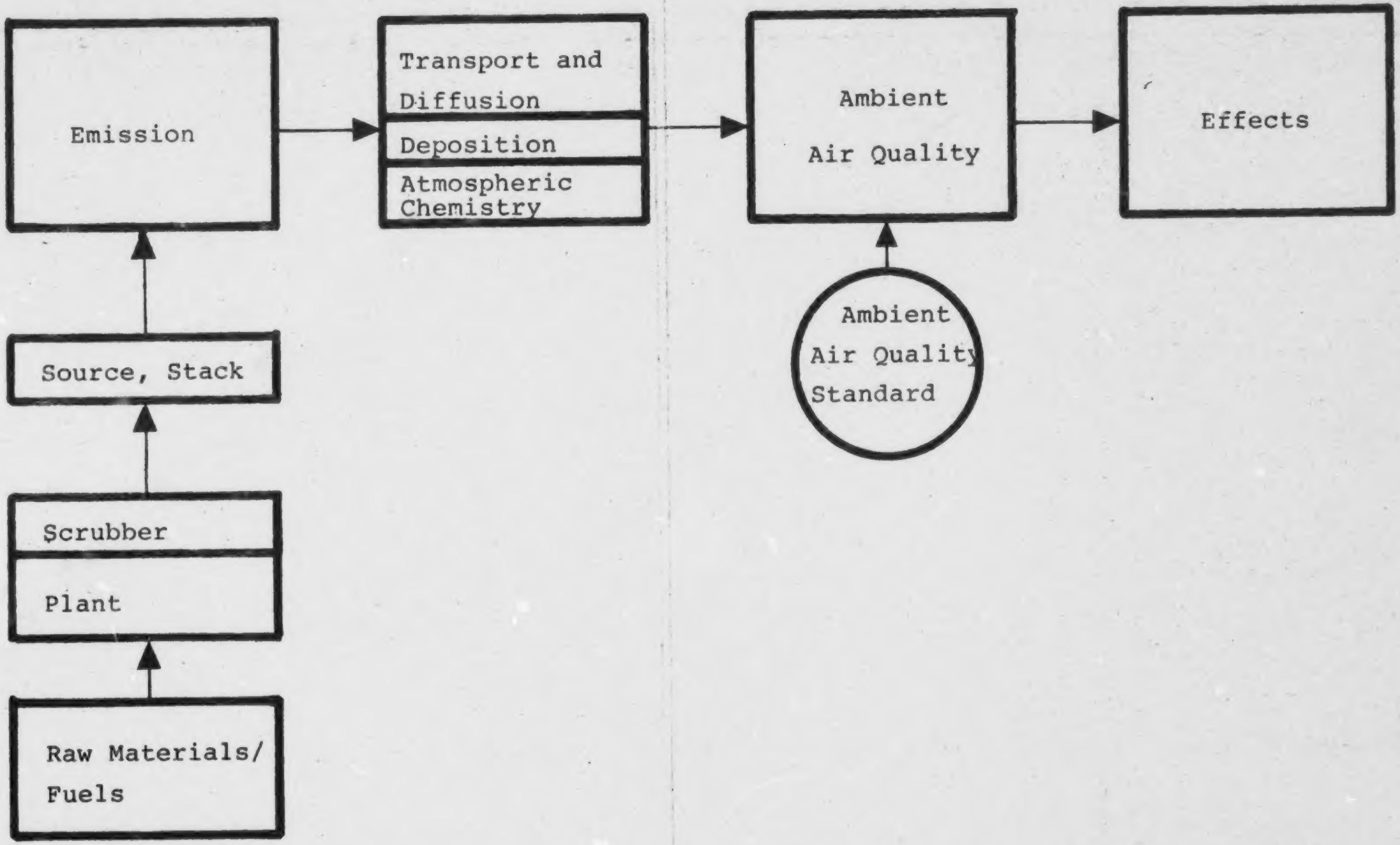
Emission
Transport and Diffusion
Deposition
Atmospheric Chemistry
Ambient Air Quality
Effects
Ambient Air Quality Standard
Source, Stack
Scrubber
Plant
Raw Materials/ Fuels

Figure 4: Air Quality Management System applying Ambient Air Quality Standards

3. ASSESSMENT METHODOLOGY

3.1 Introduction

A primary function within the AQMS is the assessment of data. These data refer to present and future situations of emission, ambient air quality, population, industrial plants, traffic, land use, topography, meteorology etc.

In some cases, these data are readily available and only have to be compiled or transformed for the needs of the AQMS, in other cases special data have to be supplied.

Some groups of data are discussed in detail in this guideline because their correct use is imperative to obtain an optimal AQMS.

3.2 Geographical Area and Land Use

The characteristics of the geographical area to which an AQMS is applied, affect the selection of the appropriate control strategy to a great extent. Therefore the area must be carefully examined and be documented.

The main items are:

- the designation of the area (name; district or part of ...),
- the boundaries and size,

- the geographical and topographical characteristics; these include:
    - the geographical location of the area, e.g. location near or at a coast with specific meteorological conditions, and the average height above sea level,
    - the relief (valleys, hills, flat terrain, forests, lakes, agglomeration of high rise buildings etc.),
- the population, industry, traffic and their spatial distribution,
- other kinds of land use within the area, e.g. farm land, recreation areas,
- the energy production and consumption patterns,
- the surrounding areas and their characteristics which may be of importance as far as they may influence the pollution inside the assessment area.

These items are closely related to land use and thus have a considerable influence on land use planning.

3.3 Source and Emissions Inventories

A primary requirement for the successful operation of an AQMS is an emissions inventory which identifies the sources of air pollution and quantifies the emissions from these sources. The emissions inventory serves as a planning tool for the development of control strategies to achieve ambient air quality goals. It provides a data base for construction of future emission scenarios to assess the impact of economic and demographic changes, or of proposed air pollution control regulations. An emissions inventory can also be used for special studies such as the assessment of the environmental impact of new sources or new technology.

A comprehensive, useful emissions inventory requires a substantial amount of accurate, up-to-date information. Source data, including source description and data on source activity, are required to properly identify sources and provide information needed to calculate emissions, determine compliance status, and to support models for calculating or predicting air quality. Measured source emissions, such as source test results, should be included whenever possible. When direct measurement of emissions for specific sources is not practical, estimations by using emission factors (average emission rates for particular types of sources) are reasonable substitutes for emission inventory purposes.

In order to produce meaningful reports, the objective of the inventory has to be specified precisely and the geographic scale, time resolution, source categories, and pollutants to be considered must be clearly defined. In an emissions inventory report national, state, regional, local totals, and the emissions for small specialized areas and grids (e.g. zones as small as one by one kilometer per side) should be included. Sources are normally classified into point and area sources with emissions reported for all relevant pollutants.

Major emphasis has to be placed on the inventory of emissions from point sources and the storage of data in automated data processing systems to facilitate retrieval. Area source data are usually included in such systems, often on a grid basis.

The principles of emissions inventories are:

- determination of the sources of emissions,
- incorporation of single sources down to the original facilities or aggregates,
- determination of emissions of air pollutants,
- recording of the time-dependent pattern of these emissions.

The term source is to be understood as the point of transition of emissions into the atmosphere. Facilities contain points where emissions are produced. These facilities may be subdivided into smaller, independently emitting parts (aggregates).

In an industrialized area, emissions normally have to be determined by a twofold approach:

- Emissions of specific sources, e.g. of power stations or of petroleum refineries, have to be determined individually, e.g. by questionairs, interviews and/or direct measurements. This is due to
    - the multitude of different technical processes within similar facilities (e.g. in Germany in an area of the size of about 600 km³ about 1.250 different emitters were counted),
    - the large number of air polluting substances,
    - the variable pattern of the emissions (start-stop procedures, break-downs, work shifts).
- Emissions caused by general point sources, line sources and area sources such as
    - transportation and other mobile sources,
    - domestic heating installations and small stationary sources

  can be estimated using a collective approach by means of emission factors.

Relatively small, but frequently occurring installations are generally considered to be part of area sources (e.g. incinerators, smoke curing, printers, dry cleaning, gasoline stations, lacquers).

The category domestic heating installations includes all devices which are used to heat buildings by burning fossile fuels.

The transportation category includes all means of transport (rail, water, and air traffic). Of major importance for a polluted area is road traffic.

3.4 Existing Ambient Air Quality

To assess the existing air quality, information is needed about the present levels of harmful or potentially harmful pollutants. This information has to be gathered for the whole area involved. The measurements or calculations performed should cover the area for which the AQMS is responsible. Measurements should not only be carried out near the emission sources in this region but should also cover the impact area around the emission sources and take into consideration the background concentration originating from local or distant sources.

An important decision is whether to locate the points of maximum concentration or to average the whole region or parts of the region. A measurement scheme to resolve the detailed pattern of maxima and gradients obviously needs a very dense network of sampling stations. A monitoring network to determine the average condition over a whole area needs sampling points at distances of tens of kilometers. The same considerations apply in relation to time because pollutant emissions and diffusion patterns are not uniform in time. Peaks and troughs of concentration are common. The frequency of sampling needed to demonstrate the daily oscillation in the levels of pollutants differs from that needed to reveal an annual average or trend over a year.

Together with the measurements of individual pollutant concentrations it is often important to gather information on the combined effects of the pollutants. To determine these effects plant indicators sensitive to one or more specific pollutants can be used. Damage patterns on leaves, retardation of development and growth of the whole plant can indicate the total effect of the pollutants. Because pollutants usually occur in combination, synergistic effects may occur which are generally estimated by biological indicators through direct effect measurements.

The amount of data to be gathered and the detail and accuracy required is often not only dependent on the number needed for assessment but is also influenced by the type of an AQMS that will be chosen. The type of system selected will indicate the type of surveillance needed to control and revise the management strategy. The measurement system needed to determine the existing ambient air quality can be combined with the expected surveillance system needed at a later stage. Just as there is a wide range of possible monitoring systems for application to different monitoring requirements, there is also a range of possibilities for assessment and surveillance of existing air quality. Although it could be advisable in some cases to have different solutions in the way of different measurement systems for assessment and surveillance, it often is more economical to select one monitoring system to perform both duties. This presupposes, however, that in the AQMS planning stage one already has an idea of the type of system that will be chosen. Before the method of data collection is decided upon, the objectives of the assessment of the existing ambient air quality should be clear.

Is it necessary to determine the reason why particular ambient air concentrations are found? Is it necessary to determine whether particular concentrations are due to special conditions of emission or transmission? Is it necessary to establish the exact location of a source of emission or to establish the contribution of a specific source to the ambient concentration found? To answer these questions, measurement of ground level concentration of pollutants only may not be enough and additional measurements or observations have to be made. The data can be collected using measurements at fixed monitoring stations, measurements made using mobile sampling or remote sensing, calculations performed using models or a combination of measurement and modeling. The choice of the means of data collection is determined in a large way by the space and time resolution that is needed.

For space resolution one can choose between:

- assessment of existing air quality at a number of spatially unconnected points,
- a number of separate areas where each area is characterized by an average value of the pollutant concentration,
- one area with assessment of the air quality as a function of space.

This means that a predetermined spatial resolution has to be specified in an AQMS. A comparable classification can be given for the time resolution, where we distinguish between:

- individual sampling where a number of samples will be taken over a specified period,
- an assessment consisting of a number of time intervals during which the concentration is evaluated independently of time and where the number of samples per time interval depend on the variations in concentration of the pollutant measured,
- an assessment with time intervals during which the time dependence of the pollutant concentration is determined.

The choice of the time and space resolution of the measurement system determines the resolution of the effects that can be usefully examined.

After a decision about space and time resolution is made, a study can be conducted on site selection and measurement methods or measuring instruments to be used. Also the equipment (continuous or intermittent) by which the measurements will be made has to be determined.

Continuous spatial measurements using optical or related methods are becoming possible. The remote sensing instruments in this field have great promise for cost effectiveness. If intermittent spatial measurements are being made, the number of samples and the sampling sites have to be made clear in the AQMS.

A major constraint in evaluating the air pollution measurements is the lack of established procedures and analytical tools which can be applied in data handling and data analysis. One of the most important points is the quality assurance of the measurements. No measurement method is completely accurate, and consequently there must be checks on the consistency of the results obtained. Records or reports presenting the results of measurement activities should contain statements as to the reliability of the data. Moreover the analysis and presentation of the data for multiple purposes requires a data storage system for reassessment purposes at a later stage. The data analysis and presentation is closely connected to the type and objective of the AQMS. The information given should answer specific questions concerning the existing ambient air quality in the region. The following information should be supplied:

- mean daily concentrations for all the pollutants concerned,
- diurnal variation of these concentrations,
- the frequency distribution of the concentrations,
- maximum values (hourly, daily),
- the major source areas responsible for the concentrations found at the receptor points.

The presentation of the above mentioned values should preferably be in graphs instead of tables. Also, maps giving the spatial distribution of the pollutants and the seasonal variation of the concentration, meteorological conditions etc. are excellent tools in describing the situation. It should be stressed that to obtain a clear presentation of data within the AQMS objective it is of the utmost importance for the data analysis to be an integral part of the design and operation.

3.5 Meteorological and Climatological Data

Concentration of air pollutants vary in space and time, partly because of the uneven distribution of sources, but also because of meteorological conditions which vary from hour to hour and from day to day. Special attention must therefore be given to the meteorological/climatological data requirements of an AQMS.

One of the important first steps in the development of an AQMS is to make an inventory of existing meteorological observing stations in the survey area. Although such an inventory will be helpful, it should not automatically be accepted as the basis for an AQMS meteorological network. The station sites were selected because of their relevance to synoptic weather forecasting, to aviation, or perhaps to agriculture, but not necessarily to air pollution. Observations at first-order weather stations include hourly values of wind (at a height of 10 m), temperature, relative humidity, atmospheric pressure, precipitation and visibility. Second-order weather stations provide twice-daily observations of maximum and minimum temperatures, precipitation and number of hours of sunshine. In some countries, there are solar radiation stations, which yield hourly measurements of the direct and diffuse components of short-wave radiation. Finally, there is a world network of rawin-sonde stations which provide twice-daily vertical profiles of temperature, humidity and wind. The ascent rate of the balloons is too rapid to yield much detail on the vertical structure of the lowest 500 m. In addition, the location of the nearest station may not be representative for the region. Nevertheless, the upper air network may yield information on the gross features of the boundary layer. In the design of a meteorological/climatological data system for an AQMS, one of the criteria to be considered is the mesometeorology of the region. Particularly when synoptic-scale winds are light and skies are clear, the mesoscale circulations can have a major effect on air quality. The existence of mesometeorological wind fields can often be estimated by:

- careful examination of topographic maps and aerial photographs and
- study of published wind roses.

The presence of a coast-line, valley or escarpment is an indication that mesoscale winds may occur. Site inspections may be helpful in confirming the existence of such flows. Because most mesoscale circulations show a day-night reversal, the wind roses are most informative when they have been prepared separately for daylight and night-time hours.

The following kinds of meteorological observations may be useful in an AQMS:

Wind Speed and Direction

Two general approaches to the problem of determining the regional wind field have been taken. First a single representative site may be selected, the assumption being made that winds at other sites are highly correlated with the reference wind. It is desirable in such cases to mount an anemometer on a television tower, if there is one at a suitable location, for use as a reference.

The second approach is to use a network of anemometers, supplementing existing stations where necessary. Such detail is required when trajectory-type models of multiple-source air pollution are contemplated.

Air Temperature

Temperatures, in particular the horizontal and vertical gradients, must be considered in developing and operating an AQMS.

Relative Humidity

There is usually no need to establish a network of stations, the data from a single representative site being adequate for an AQMS.

Cloud Cover and Solar Radiation

In most cases, existing weather stations can provide representative observations of cloud and/or of hours of bright sunshine. There may also be locations where solar radiation is being measured. Of special interest is the ultraviolet waveband that causes photochemical reactions. There are reasonable correlations between UV-radiation and total solar radiation so that only in the case of research investigations is it necessary to monitor the UV-waveband separately.

Precipitation

The occurrence of precipitation and some estimate of the amount may be obtained from existing weather stations. In some AQMS, there is special interest in the chemical composition of precipitation.

Visibility

Visibility is measured routinely at first-order weather observing stations.

Vertical Profile Data and Mixing Heights

Of special interest to an AQMS is the structure of the planetary boundary layer (the lowest 1 km or so) and of the surface mixed layer (the lowest few km in some cases, depending on the vertical extent of daytime convection). These data cannot be obtained from ground-based sensors but require:

- rawin-sonde data analyzed to yield afternoon maximum mixing heights, early morning urban mixing heights, and mean transport winds through the surface mixed layer; this information is valuable in climatological studies when interpolation between stations perhaps 500 km apart is used,
- minisonde data to obtain necessary information on vertical profile data and mixing heights,
- a third alternative is to measure vertical profiles on tall television towers,
- finally, remote-sensing devices such as lidar, sodar and acoustic sounders can be used to monitor the mixing height; these instruments have not yet been developed operationally although they are valuable research tools.

The minimum meteorological program that could be envisaged in support of AQMS is one which depends entirely on existing meteorological stations.

A major AQMS should include the following measurements:

- surface winds from a network of anemometers,
- profiles of wind and temperature from a tall tower,
- regular determinations of the height of the surface mixed layer, using minisondes, remote sensing devices or aircraft,

- measurements of solar radiation and its ultraviolet component,
- turbulence sensors (bivanes, sonic anemometers, etc.) located on tall towers.

3.6 Atmospheric Chemistry Data

For many reasons, there is need for atmospheric chemistry data in an AQMS.

In addition there is an increasing need for supplementary information, as air quality control widens to include several new kinds of problems:

- regional oxidant effects due to the photochemical production of oxidants,
- acid rains,
- brown hazes over cities,
- pollutant removal processes,
- long-range transmission of air pollutants.

The information requirements associated with each of these problems are discussed in the following subsections.

Regional oxidant effects

Photochemical oxidants were first associated with the city of Los Angeles, California, but they have since been found in almost all parts of the world. The necessary precursors are oxides of nitrogen and reactive hydrocarbons, and there must be sunlight.

Oxidant concentrations are often lower in cities than in the surrounding countryside, for two reasons:

- Photochemical production of oxidants takes several hours, so that maximum concentrations may occur more than 50 km downwind of sources of precursors
- the rate of oxidant destruction is greater in cities than in the countryside. Concentrations of NO and of aerosols are higher in cities, and these substances destroy oxidants; in addition, there is more turbulence and a more rapid rate of delivery of oxidants to the surface of the earth in cities, also speeding up the destruction rates.

One of the air chemistry data needed therefore are oxidant measurements in the surrounding rural environment.

Acid rains

Acid rain is a large-scale phenomenon, the deposition sometimes occurring more than 1000 km from source regions. The problem is of special concern in target areas where:

- The soil is naturally acid (podsolic) and is therefore sensitive to additional acidic inputs,

- orographic lifting over high ground triggers precipitation, wash-out of pollutants from a polluted air-mass. If rain were to fall while the air was in transit from the source regions, the pollution would be washed out before reaching the target area.

Because acid rains are associated with largescale meteorological processes, data are required from a rather large area. With daily sampling time, estimates of source regions for wet deposition can be made, based on a trajectory analysis applied to the daily weather maps.

Brown hazes over cities

The brown haze layers that sometimes occur over urban areas can be attributed to at least two effects: the absorption by NO_2 of blue wavelengths of skylight and the selective scattering und absorption of light by atmospheric aerosols and particulates. The brown haze may occur even when air quality standards for NO_2 and suspended particulates are met.

Removal processes for atmospheric pollutants

Four processes contribute to the removal of pollution from the air over a region:

I. advection to neighbouring regions,

II. chemical transformations into other species,

III. absorption by the underlying surface (dry deposition),

IV. precipitation wash-out (wet deposition).

As part of an effective AQMS, there is an increasing requirement for daily estimates of the magnitudes of these removal rates.

Process number I (advection) has normal meteorological data requirements.

The information needs associated with process number II (chemical transformations) are as follows:

- knowledge of chemical reactions, and of the numerical values of the rate constants (usually obtained from laboratory experiments),
- measurements of the concentrations of the relevant substances (usually obtained from networks of monitoring stations but supplemented with aircraft surveys on selected days).

The third removal process, and perhaps the most difficult to quantify with any precision, is dry deposition. The rate of depletion of pollution at the surface of the earth is a function of a number of factors, including:

- micrometeorological factors such as wind speed and temperature gradient,
- wetness of the surface,
- pH-value of the surface,
- surface roughness,

- physiological factors such as the degree of opening of the stomata of leaves,
- in the case of particles greater than 20 μm in diameter, the fall velocities of the particles.

For a small region (only a few kilometres in diameter), the effects of dry deposition need not be considered except in the case of large-particle fallout. For large regions, however, it is almost always desirable to include the losses due to dry deposition, even if only in a crude empirical way.

Long-range transmission of air pollutants

Tall chimneys and regional land-use planning were frequently used to solve local and regional air pollution problems. However, these strategies result only in deposition of effluents over a wider area. The air quality may remain satisfactory at long distances from source regions because of atmospheric dilution, but there may be slow accumulations of harmful substances (e.g., heavy metals, pesticides) in other media (lakes, soils, glaciers) over decades.

Because of decreasing supply of oil and natural gas, the amount of coal used by power stations is expected to increase during the next decade. Thus there is likely to be an increase in long-range transmission of sulphates, nitrates and heavy metals, and of acid rains.

4. STANDARDS AND CRITERIA

4.1 Introduction

Most AQMS are based on either emission standards, product standards, air quality standards or a combination of all three. In any case, the standards are always measurable, enforceable, and legally binding. Thus, emission concentrations or mass flow rates, fuel compositions, and the concentrations of xenobiotic substances in the ambient air are to be reduced through the development and enforcement of such standards.

Criteria, on the other hand, are normally the results of extensive background studies (e.g. detailed dose/effect investigations). The criteria themselves are not legally binding but are nevertheless of great importance because they define the relationship between exposure of a receptor to pollution and the consequent effects (e.g. health risks or risk of ecological damage). Thus criteria documents become a partial or complete basis for the standards finally selected for the AQMS. Criteria documents are generally developed for use in selecting ambient air quality standards although similar scientific background studies may be used to describe the range of feasible control techniques available for abatement of a given pollutant. These control technique documents provide an analogous basis for product and emission standards. The finally selected standards may or may not be based solely on the criteria documents since economic factors and social priorities often influence this choice. Nevertheless the selected standards must be in harmony with pollution monitoring and analysis techniqes. The following paragraphs discuss some problems and solutions in this subject area.

4.2 Emission Standards and Related Control Technology

Emission standards are a widely used means of regulating emissions. Generally, they are either tailored to specific industrial processes or plants or to specific pollutants. Emitting plants may be subdivided into several categories of similar plants, for example into coal-fired power plants, steel mills and sulfuric acid plants and standards are defined for all members of the category. Alternatively, the standards may be defined for specific pollutants without relation to the emitting source. This is often the case especially for toxic substances.

Emission standards normally limit either:

- the concentration of a certain pollutant in effluent gas, expressed for example as of pollutant quantity per volume of gas;
- the mass flow rate of a certain pollutant, expressed as pollutant quantity per time period;
- the opacity of a plume, expressed in Ringelmann numbers;
- the emitted quantity of a certain pollutant per unit of product.

The formulation of emission standards is either governed by:

- the concept of best available control technology or
- the concept of best practicable control technology.

The first concept imposes the most efficient control technology to all members of a defined category of plants, regardless whether they are old or new or whether they are located in polluted or in unpolluted areas.

For being "available", it is sufficient that a technology has proven its efficiency on a pilot scale and it can be expected that it will work adequately on a large scale basis. Economic aspects of a single plant related to application of advanced technology are not taken into consideration in assessing the state of the art. By this, the introduction of advanced control technologies is accelerated and the standard can be made more stringent as soon as a new control technology is available.

The concept of best practicable control technology implies both best available and economically feasible technology. It is inherent in the term "feasible" that the cost will be within the reach of industry to avoid undue economic hardship. In evaluating what is economically feasible, the environmental effects of the pollutants to be controlled are taken into consideration, either by implication or expressed explicitly.

In both concepts the uniformity of emission standards with respect to all plants within the category and to all locations leads to simplicity in the formulation and the enforcement of the standards.

It is obvious, that the prevention of pollution problems before they occur is inherently less costly than forcing emission controls onto facilities after they are built and operating. This leads to different requirements for new and existing plants. New plants must meet the standards as soon as they start operation, a requirement, which can effectively be enforced by means of a permit system.

The application of advanced emission standards to existing plants, on the other hand, may be extremely difficult and normally requires a larger time period, during which compromises between the responsible agency and industry may be necessary.

The following tables give some examples of emission standards:

Table 1	plant-related emission standards
Table 2	pollutant-related emission standards

Table 1: Examples of Plant-Related Emission Standards (Federal Republic of Germany)

Type of Plant	Pollutant	Emission Standard	
1. Combustion of solid fuel			
- large water room boilers	Particulate matter	300 mg/m$^{3\,*)}$	
	Carbon monoxide	250 mg/m$^{3\,*)}$	Plume opacity must be better than No. 1 of Ringelmann chart
- water tube boilers (with flow rate of up to 5000,000 m³/h waste gas)	Particulate matter	150 mg/m$^{3\,*)}$	
	Carbon monoxide	250 mg/m$^{3\,*)}$	
2. Waste Incinerators			
Incinerators with a waste input stream of up to 0.75 t/h	Particulate matter	100 mg/m$^{3\,*)}$	
	Carbon monoxide	1 mg/m$^{3\,*)}$	
	Chlorine compounds (measured as Cl^-)	6 kg/h	
	Fluorine compounds (measured as F-)	0,2 kg/h	
Incinerators with a waste input stream of more than 0.75 t/h	Particulate matter	100 mg/m$^{3\,*)}$	Plume opacity must be better than No. 1 of Ringelmann chart
	Carbon monoxide	1 mg/m$^{3\,*)}$	
	Chlorine compounds (measured as Cl^-)	100 mg/m$^{3\,*)}$	
	Fluorine compounds (measured as F^-)	5 mg/m$^{3\,*)}$	
3. Blast Furnaces	Particulate matter	20 mg/m$^{3\,*)}$	

* cubic meter of waste gas (minus content of water vapour) at 0 °C and 1013 mbar

Table 2: Examples of Pollutant-Related Emission Standards (Federal Republic of Germany)

Pollutant	Emission Standard	
		for a pollutant mass flow rate of more than
Particulate Matter		
Lead and its soluble compounds	20 mg/m^{3}*)	0,1 kg/h
Mercury and its compounds	20 mg/m^{3}*)	
Quartz with a particle size smaller than 5 µm diameter	50 mg/m^{3}*)	1 kg/h
Zinc and its compounds	50 mg/m^{3}*)	
Ammonium compounds	75 mg/m^{3}*)	3 kg/h
Bitumen	75 mg/m^{3}*)	
Gaseous Organic Compounds		
Acrolein	20 mg/m^{3}*)	0,1 kg/h
Phenol	20 mg/m^{3}*)	
Butadiene	150 mg/m^{3}*)	3 kg/h
Naphtalene	150 mg/m^{3}*)	
Acetone	300 mg/m^{3}*)	6 kg/h
Methanol	300 mg/m^{3}*)	

* cubic meter of air (minus content of water vapour) at 0 °C and 1013 mbar

4.3 Equipment Standards and Product Standards

Air pollution is to a large extent not only caused by industrial plants but also by a large number of smaller sources for example by space heating devices or motor cars. These sources may, especially in densely populated areas, contribute significantly to air pollution. If it is impractical to subject the numerous smaller sources to individual licensing and compliance testing, it may be effective also to incorporate control measures during the design and construction/production phase.

Standards which specify design characteristics are called equipment standards. Standards which specify the composition of materials are called product standards. Agencies frequently use equipment standards to specify incinerator designs or afterburner operating requirements. Fugitive emissions can be eliminated effectively by applying equipment standards to gasoline vapor-recovery equipment or to petroleum storage tanks by specifying the storage vessel design or even the color of vessel paint.

A successful equipment standard must allow and even encourage the emitter to apply equivalent controls other than those specified. This flexibility avoids a static policy that would impede innovation, stifle the development of alternative controls, and increase costs unnecessarily. For example, a three-chamber incinerator may be specified in the standard whereas the emitter might prefer to install a pyrolysis unit with product recovery. Such an alternative should be allowed if the potential user can demonstrate that the proposed system is indeed equivalent in emission control.

Other products used in large quantities and capable of causing serious air pollution problems are fuels, gasoline, process materials, paints, plastics, etc. Considerable emission reduction can be achieved by specifying the maximum allowable content of certain substances. These substances may e.g. be natural product constituents, such as sulfur in coal or oil, or additives in order to achieve certain product characteristics, such as lead tetraethyl in gasoline to improve combustion. These substances may lead to air pollution either during product use, waste incineration or other stages of a product live cycle. Examples for this type of product standards are the limitation of sulfur content in coal or oil, of additives in gasoline, of organic solvents or asbestos fibres in paints, of vinyl chloride in polyvinyl chloride (normally not causing health risks by air pollution but by food contamination).

Product standards may also be prohibitive standards; an example is the prohibition of the use of spray cans containing chlorinated hydrocarbons as propellants. Examples of product standards are given in Table 3.

With respect to the composition of fuels or process materials, often an alternative is offered to the emitter in order to achieve flexibility in pollution control. For example, the use of high-sulfur fuel might be allowed, if effective desulfurization equipment is installed.

Table 3: Examples of Product Standards
(Federal Republic of Germany)

Product	Pollutant	Product Standard		Date of Coming into Force
Gasoline	Lead	0,40 g/l	(at 15 °C)	January 1, 1972
Gasoline	Lead	0,15 g/l	(at 15 °C)	January 1, 1976
Gasoil	Sulfur	0,55 %	(on weight)	May 1, 1975
Gasoil	Sulfur	0,50 %	(on weight)	May 1, 1976
Gasoil	Sulfur	0,30 %	(on weight)	January 1, 1979

4.4 Air Quality Standards and Criteria

In most air quality assessment or modeling studies it will be desirable, if not essential, to compare the observed/calculated concentrations with levels which have been found to be associated with effects on health, animals, vegetation or materials. Indeed, the principal purpose of an AQMS may very well be to ensure compliance with air quality standards or objectives.

In general, AIR QUALITY CRITERIA contain detailed documentations of pollutant concentrations found, through scientific investigation, to be associated with effects. There can be acute effects which cause an abrupt change in the health or condition of the receptor; in extreme instances even death can result.

There can also be chronic effects whereby an impairment in the health or condition of the receptor can occur due to exposure over a long period of time. In some cases the effects can be temporary, virtually disappearing after the period of exposure. In other cases the effects can be cumulative, with the pollutant being accumulated in certain organs of the human body. The time for which the critical pollutant concentration (or threshold value) must be exceeded for a specified effect to be observed is of paramount importance and is an integral part of the dose-response relationships.

Examples of air quality criteria are:

- The WHO acute effects levels of 500 μgm^{-3} smoke and 500 μgm^{-3} SO_2 daily average and the WHO chronic effects levels of 100 μgm^{-3} smoke and 100 μgm^{-3} SO_2 annual average,
- sensitive plants will exhibit damage if exposed to ethylene concentrations of 0.1 to 0.5 ppm for a few hours,
- corrosion of steel is directly related to ambient concentrations of SO_2. In one series of experiments the absolute weight loss over a 12 month period was 30 % higher in an area with a mean SO_2 concentration of 350 μgm^{-3} than the loss in an area with a mean concentration of 100 μgm^{-3},
- cadmium oxide fume concentrations of about 5 mgm^{-3} for an 8-hour exposure period are likely to cause acute fatalities in man while calculations indicate that accumulation in the kidney could become critical after 25 years exposure to average concentrations of cadmium-oxide in air of approximately 10-20 μgm^{-3}.

It should be borne in mind that pollutants may act synergistically, which means the combined effects of two or more pollutants may be more severe than the simple addition of the effects of the pollutants considered independently. For example, it is shown that synergistic effects occur by combinations of sulphur dioxide with ozone or nitrogen dioxide.

Air quality criteria can be used for comparison purposes or as a basis for AIR QUALITY STANDARDS. In either case it is essential that the specific pollutants causing the effects and the exposure times are fully recognized when implementing the AQMS. It is evident that, where possible, the monitoring/modeling system should monitor/model the specific pollutant referred to in the standard. For example, there may be little point in measuring/calculating total suspended particulate concentration if the standard is concerned with particulate sulphate or with particle sizes smaller than 2 to 3 μm and neither can be directly related to the total suspended particulate (TSP) value. Vegetation or material damage is usually more closely related to the rate of uptake of the pollutant through, for example, dry deposition or impaction and subsequently by absorption or adsorption. In such cases one should be more concerned with the flux into the receptor (immission) than the ambient air concentration and atmospheric turbulence or particle size can be just as important in these circumstances. This must be borne in mind when conducting the relevant assessment/modeling study.

Air quality standards are defined legally, are enforcable, and should be based on appropriate air quality criteria. However, the standards need not be identical with the criteria documents because in deciding on acceptable air quality socio-economic priorities and other factors may also be considered.

In the selection of air quality standards some important practical points are frequently overlooked. Specifically, the standards may be formulated in such a way that errors in measurement, unrepresentativeness of monitoring stations, varying meteorological conditions, and modeling uncertainties are not fully recognized. Because of these factors it is impossible to state with absolute certainty that a given level, e.g. daily mean or hourly figure, has not been exceeded or will not be exceeded in the future unless the measured or calculated value is substantially less than the standard. Indeed, very strict quality control may have to be introduced to ensure that a certain figure is not exceeded for a very small proportion of the time. (For a very toxic pollutant this may, however, be justified).

Many of these practical problems can be overcome by expressing the standard, where appropriate, in terms of a cumulative frequency. For example, the standard might be stated in terms of an annual average or median value not to be exceeded and a higher value not to be exceeded more than X % of the time. Typically X might be 2 or 5. The WHO long term goal for SO_2 is an example of such a formulation. The advantage of such a formulation is that the X % is much less sensitive to the variations and uncertainties referred to above than is a single maximum figure. Nevertheless, uncertainties will remain and it is essential that those responsible for reporting the monitoring data and model results incorporate comments on the limits of uncertainty. For example, the 98 percentile value at a particular monitoring station may be reported to be correct to within 10 % of the true value with 95 percent confidence. It should be noted that concentrations computed using a model will, in general, be less accurate and subject to greater uncertainty. Such limits of uncertainty are perhaps not too difficult to quantify for the location where the measurements have been made or for which the model calculation has been made. However, it will often be necessary to extrapolate or interpolate spatially, particularly if there are steep gradients in pollutant concentration and the monitored/calculated values are close to the standard. Consideration then needs to be given to quantifying the uncertainties introduced by spatial variability. It may be acceptable to provide spatial averages, say for each 1 km^2 area. In some cases such averages may be regarded as inadequate but it could be impracticable or prohibitive in cost to provide the desired spatial resolution.

5. ECONOMIC ASPECTS OF AQMS

5.1 Introduction

The resource expenditures needed for designing and implementing an AQMS are dependent on numerous factors. The geographical size, for example, has major influence on costs as does the number and density of population within the area.

There are generally two categories of AQMS costs: initial and operating. Initial costs are those expenditures needed to first establish an adequate AQMS wheras operating costs are the annual resources required to successfully maintain an already established AQMS.

Computer software development and purchase of monitoring equipment are two examples of AQMS components with high initial costs but done on a one-time basis.

Scientific obsolescence of equipment, replacement, data processing, and manpower training programs are examples of AQMS activities with high operating costs.

Economic considerations for three major AQMS elements (ambient air monitoring, emission inventories and modeling) are discussed in detail in the following paragraphs.

5.2 Ambient Air Monitoring Costs

The accuracy, quantity and availability of data desired by the AQMS managers are important parameters for estimating the capital and operating costs associated with the monitoring network. Often, the projected costs of monitoring are optimized by evaluating operating plus capital costs of alternative measurement techniques. For example, highly automated, continuous monitoring equipment entails high initial expenditures but relatively low maintenance and training costs wheras manual methods have the opposite characteristics.

Interaction of the AQMS data-monitoring personnel with the equipment involves a continuous and expensive training program. In the economic evaluation of alternative systems, future inflation and wage levels are especially important parameters.

For example, it was calculated in the Netherlands that a surcharge on oil and gas collects hfl 56 Million to be used for all activities to keep the air sufficiently clean. Ambient air monitoring, including data-processing, takes one third of this amount. If the whole immission monitoring is automated the costs could be hfl 0.002 per liter gas. Manual analyses if taken 4 times per day would cost hfl 20 per sample; automated measuring takes hfl 4,27 per one hour averaged measurement.

The extension of the area involved is an important factor. For large areas automatic data acquisition and transmission normally is the most economic solution. The telecommunication and automatic data acquisition costs are substantial part of total costs.

In the Netherlands the following costs were calculated for the Dutch national ambient air monitoring network:

Investment hfl 37.000.000

Assuming a five years economic life time, this means:

depreciation costs per year	hfl 8.880.000
interest (8 %)	
servicing	hfl 2.400.000
labour costs	hfl 900.000
energy and printed matter	hfl 100.000
telefone and terminal use	hfl 1.600.000
housing and overhead	hfl 500.000
Total costs per year	hfl 14.380.000

The investment includes
193 SO_2 monitors
34 O_3 monitors
83 NO_x monitors
27 CO monitors
44 monitors for wind direction
44 monitors for wind speed

Assuming 22 one hour averaged measurements per 24 hours, 360 days per year (including down time, calibration and maintenance) this would mean 3.366.000 single measurements. So the costs per single measurement could be estimated to be c. hfl 4.27.

In making cost estimates, investment and operating costs must be considered separately. The average operating costs per year should be taken, if one wishes to compare surveillance systems with non or semi-automated monitoring installations.

These costs, however, are not decisive on their own because one has to balance them against the results, and expected benefits for the policy making authorities.
More sophisticated systems have a relatively short economic lifetime with high depreciation costs but relatively low costs of servicing. This should be investigated very carefully before installing or changing a monitoring system.

The networks of pollution monitoring and analysis techniques must correspond to ambient air quality standards.

In this context, ISO has set up the Technical Committee ISO/TC 146, Air Quality, to deal with the publication of international standards concerning tests methods and methods of analysis, including sampling and definition of terms. ISO is also considering what information has to be available before a method can be recommended as an ISO standard and is also examining the problems connected with the development and use of reference methods.

5.3 Costs of Emissions Inventories

These costs depend of course on the size of the area and the amount of data to be collected. Cologne, in the Federal Republic of Germany, estimates that initially an inventory for an area of 1.5 million people, including 1000 substances emitted with more than 1 kg per year costs about DM 6.000.000. The update has to be done about every five years.

Other estimations of the annual running costs (depending on the size of the state) per year:

Nordrhein-Westfalen	DM/a	1.500.000
Bayern	DM/a	1.000.000
Hessen	DM/a	1.200.000
Rheinland-Pfalz	DM/a	500.000

In the Netherlands an emission-registration project started in 1974 and is expected to be finished in 1980. About 9000 factories will be registered, 3000 of them after personal visits; the other, smaller ones, by telephone enquiries. The total number of entries is estimated to be 110.000, being a multiplication of the number of plants and the number of different pollutants per plant. In the average, about 11 to 12 pollutants are registered per factory. The total costs are estimated to be:

Labor:	enquiries and governmental support	inclusive overhead	hfl	35,28	million
	data-processing		hfl	0,60	million
		±	hfl	36	million
	Estimated tax		hfl	6	million
			hfl	42	million

For the Netherlands, having a population of 14 million people approximately, this means that the costs, just mentioned for Cologne could be multiplied by 9 to 10. As a steadily rising wage-level is included in the Dutch figures, both figures seem not to be fully in line with each other. When this primary inventory is finished, the follow up starts. Then the costs might be estimated as being about 10 % of the year costs of the first set-up. The data bank is presumed to be reviewed any 3 years. It should be mentioned that the hfl 42 million, which were calculated above, are the total costs for the 7 years.

The above values include data verification and data processing. Emission inventories are often based upon specific emission tests of individual sources (e.g. source tests and continuous stack monitoring). Germany has estimated the following costs for a first information to get emission data from individual facilities:

Steamboiler 10 ton steam per hour	DM	1.600
Steamboiler 2000 ton steam per hour	DM	4.000
Foundries processing 5 - 10 ton iron per hour	DM	35.000
Oxygen steelworks processing 200 ton/ run out	DM	10.000
Cementindustries, processing 3000 ton/day	DM	20.000
Mineral oil refinery processing about 3.000.000 tons raw oil per year	DM	40.000

The example of a petroleum refinery illustrates the relative costs of pollution monitoring. Assuming 30 refineries processing 150.000.000 tons of raw oil per year, the supplementary costs per liter are as low as DM 0,00001 per liter.

Sometimes emissions from a factory can be determined easily using emission factors. For example total emissions of sulphur-dioxide from a fossil fuel fired boiler can be easily calculated when the quantities of input (coal burned) or output (eletricity generated) are available.

When operating and maintenance procedures significantly affect the rate of emission routine inspections, examination of the abatement equipment can no longer adequately determine the emission rate. It then becomes necessary to rely on some form of direct measurement.

AQMS managers must regularly check local emission measurements within the context of the AQMS objectives. It is, therefore, in no way surprising that in countries with major problems such as the USA, Western Germany and the Netherlands technology is stimulated to develop automated monitoring systems, giving continuous signals with as little human intervention as possible.

Since information on sources and emissions are used by many organizations within the AQMS there may be a tendency for these groups to independently collect their own data and use them for their own purposes. Moreover, unless strict management controls are maintained, such data may be discarded or otherwise lost for use by other groups within the AQMS. For example, the AQMS enforcement or research organizations may conduct source tests on suspected polluters yet neglect to supply such data for incorporation into the emission inventory. If this situation is avoided through proper AQMS, the emissions inventory can be substantially and routinely improved with essentially nearly no additional costs for the AQMS management. In the USA, for example, it is estimated that 95 - 97 % of emissions inventory costs are associated with the initial acquisition and correction of data and only 3 - 5 % associated with format conversion and data processing.

5.4 Costs of Modeling

In Great Britain it was estimated that the development of a model for an area of 40 square kilometers, containing about 3000 sources and based on 40 receptor points, costs about £ 60.000 and the application of the model another £ 30.000. Again this is comparable with a larger area around Cologne in Germany where the estimated total costs of a similar model were DM 500.000.

It should be emphasized that the operating costs of modeling decreases substantially once the modeling programs are developed. These cost reductions occur for a number of reasons but are primarily due to the relatively large costs already connected with data collection, model development, and computer equipment over the previous period. Because of this situation and the widespread application of developped models, the USA has experienced marked reductions in modeling costs. In 1977 these costs appear to be substantially less than those reported by the U.K. and Germany. This trend is expected to continue in the USA and will probably also be observed in countries as they establish and operate AQMS.

Because of the relatively large development costs, it is especially beneficial for an AQMS to collect modeling information and software from other organizations with established modeling systems and to integrate such material for their own particular use.

6. STRATEGY PLANS

6.1 Introduction

An air pollution strategy plan is a master plan that provides a solution to a municipal, state, provincial, national or international air pollution problem. A strategy plan is the final and most difficult part of an AQMS. First a strategy plan should be based on ambient air quality standards, on projected emissions and ambient air quality and on the results of the assessment studies. The ultimate decision has to include also the interactions with other environmental media (land use, water pollution, etc.) and economic aspects. The selected measures of the strategy plan must be legally enforcable, practically and technically feasible.

Because of technical and/or economic reasons it is sometimes necessary to find specific solutions to existing industrial plants. Improvement of these plants requires a longer time period and this must be taken into consideration in preparing the strategy plan.

Generally speaking the selection of the initial strategy plan should be based upon four considerations, most of which have been already described in previous chapters

- determination of air quality,
- determination of the sources of air pollutants (emissions inventory),

- modeling and projecting of air pollution emissions to forecast future air quality,
- formulation, implementation and enforcement of air pollution control.

The strategy plan must be reviewed periodically and revised as appropriate.

6.2 Major Strategy Plan Options

The need for a strategy plan depends on the results of the determination of emissions, on the anticipated concentrations and the effects of the air pollutants found.

In some cases the establishment of a strategy plan can be very important if many different air pollutants occur simultaneously, causing synergistic effects or secondary air pollutants (e.g. photochemical air pollutants). At times it will not be sufficient to concentrate on criteria pollutants only, but it will be necessary to include all information available about other pollutants. The emissions inventory and the results of simulation modeling provide information on the sources of the different air pollutants. It is necessary, then, to consider major sources outside the area of concern because their emissions may be transported over long distances and impact the problem area of the AQMS.

A strategy plan must not be established only on the basis of the present situation. Future emissions must be projected taking into consideration the realistic development of industrialization, population and traffic pattern as well as future land use. Changes in land use may not only affect emission patterns but may also have an influence on local wind fields and on the intensity of transport of fresh air into a polluted area. Diffusion models can be used to predict future ambient air quality.

To be effective, a strategy plan must contain legally enforceable measures to improve ambient air quality with schedules and time tables for compliance with the plan's objectives. The measures appropriate for the area of concern will depend on the objectives of a control plan's objectives and the specific local situation. Appropriate measures are emission control, land use planning, siting of industrial plants, planning of highways and roads, designing of green belts and buffer zones, and the development of alternative energy sources and supply systems.

If air pollution is caused mainly by stationary industrial sources, very often a significant reduction of emissions will be required to accomplish the control plan. This can be done by technical measures such as the installation of more efficient gas cleaning devices, application of new technologies, and the usage of less polluting fuels and raw materials.
In many countries a uniform procedure for granting licences under a number of different environmental protection laws is now being discussed and in some cases being implemented. In doing so, great interest has been expressed in environmental impact assessment as a potential instrument for integrated planning. In heavily polluted areas a new source

should only be constructed if emissions from existing sources are reduced by an equivalent amount.

For large metropolitan areas, planning and choice of the energy system is highly important. If dust, smoke, and sulphur dioxide are the main air pollution components, a significant improvement of air quality may be achieved using natural gas instead of coal or fuel oil. The installation of a remote, centralised heating system leads to an improvement of air quality in areas dominated by low level emissions from small single space heating equipments. Other measures are necessary if air pollution is mainly caused by traffic emissions. In these cases, improvement may be achieved additionally by restriction of traffic densities in certain areas or by providing a low emission public transport system. The construction of new highways and roads outside the area of concern may be an effective measure for lowering traffic densities in the most polluted districts. Relocation of traffic or of industrial plants has to be planned extremely carefully. A poorly thought-out plan may not achieve a net reduction in total emissions because emissions are transferred into other areas, possibly causing new problems or aggravating existing problems.

A new procedure adopted more and more in regional planning is the proposal of alternatives which usually differ according to the methods of protecting the quality of the natural environment. Legislation must recognize and promote the coordination between the national, regional and local levels of government and the procedures for citizen involvement and appeal. A small AQMS, perhaps implemented by local authorities, sooner or later becomes part of a larger regional, national or international AQMS because of the long-range transport phenomena. Several alternatives for land use must be considered in light of current and future expected air quality. All other parameters of environmental quality (water, soil, noise etc.) have importance. But as air quality is influenced by changing meteorological conditions (and is perhaps most sensitive to long-range effects), it is also one of the most difficult parameters to control in land use planning.

Existing land use and existing air quality are facts. Long-term planned land use and long-term desired air quality are objects to be managed. Both are indispensable parts of a control strategy plan. They are all the more important because our knowledge of the temporal and spatial relationship between emissions and their effect is incomplete. Temporal effects may be immediate or cumulative over long periods; spatial effects may vary from local impacts to effect over long distances.

A strategy plan should also include the installation of a monitoring system for the emissions of stationary and mobile sources, ambient air quality and relevant meteorological parameters. An information system for economic, demographic and topographic data should be established. These data are of special importance for predictions of emissions and air quality and for the revision of strategy plans.

6.3 Projected Emissions and Ambient Air Quality, including Impact Statements

Detailed forecasting methods are also needed. In this context the emission forecast not only provides future estimates based upon today's strategies, but also provides an ideal mechanism for comparing effects of various control strategies. Thus, emission forecasting is a vital management tool and has an integral role in the planning and evaluation activities of control agencies. A good forecasting system utilizes the most current emissions inventory data and assures that the most current data are always utilized for predictive purposes.

Dispersion models are being developed to provide mathematical relationships between air pollutant emissions and ambient air quality. These models can be used to relate the contributions from different source categories and configurations to ambient air concentrations. Consequently, they can be used to evaluate the various proposed air quality abatement strategies, viz.:

- Identify the most effective way of controlling existing emissions if it is decided that existing air quality needs to be improved,
- Quantify the effect of projected emissions, including industrial/residential growth, and the effects of emission control options.

In principle, using dispersion models, air quality can be projected for as far forward as reliable emission estimates can be made. These modeling techniques are therefore integral parts of selecting control strategies, of revision of strategy plans and of impact statements.

Most projection studies are primarily concerned with predicting the mean values of the pollutant concentrations in ambient air and the probability of occurrence of some higher concentrations. In many applications, therefore, the model must be capable of predicting the temporal frequency distribution at any given location. For example, dispersion models can be used to compute seasonal or annual mean values, or medians with reasonable accuracy, but the accuracy may deteriorate at the higher end of the frequency distribution and therefore the prediction of the higher percentiles will be less reliable. In making these projections it is commonly assumed that the recent climatological/meteorological conditions will prevail in the future. However, these conditions may very well exclude extreme weather conditions which may occur occasionally (e.g. once every 5 or 10 years) and which can result in exceptionally high concentrations of pollutants for periods of several days. The manager of the AQMS may need to take such events into account when projecting air quality and when selecting the control strategy.

When real time control of ambient air quality has been selected as part of the control strategy (i.e. load reduction, load shifting or fuel switching), it may be necessary to have a model with the capability to predict concentrations on an hour-by-hour basis. In selecting the model it is important to keep in mind the type of results required for comparison with air quality objectives or standards and the acceptable limits of accuracy and of spatial and temporal resolution. These requirements will govern, or may themselves be governed by ambient or source monitoring, emission and meteorological data availability or the extent to which validation of the model has been successful.

As mentioned earlier, impact assessment is a potential instrument for integrated planning but has inherent difficulties due to a lack of baseline data and appropriate methodologies. Interests are conflicting and short-term and long-term considerations sometimes are divergent. The usefulness of modeling is important. However care must be taken in using very elaborate techniques when they depend on individual subjective assumptions.

Simple standardized assessment methods have to be recommended. Impact reports can play a real and valuable role in environmental management. They encourage an integrated approach, foster public participation and may prevent decisions being made without full knowledge of the environmental impact.

Within the framework of an AQMS an impact report should contain information about the local situation, the focus of implementation and the means for implementing the proposal, the environmental consequences which are to be expected, the alternatives, a costbenefit analysis, the link with existing policy and a list of the sources from which the information was obtained.

Air quality impact statements can be defined as public documents, intended for decision making, in which the impact of proposed activities on air quality in the near and perhaps the more distant future is described. The physical system (the whole of natural environment, artifacts and localized activities) is in constant interaction with other ecological, economical and social systems.

6.4 Selection of Control Strategy

Selection of control strategy is a step-by-step optimizing process. It consists primarily of the following steps:

1. Assessment
2. Apportionment of ambient air quality to sources
3. Identification of available control techniques
4. Integration of control techniques in alternative strategy plans
5. Selection of "best" plan

Each of these steps is discussed in detail below:

Step 1: Assessment

Assessment includes the collection, handling, evaluation, analysis and presentation of data necessary to understand the air pollution problem of the area and its causes. These data normally refer to geography, topography, land use, sources and emissions, ambient air quality, meteorology, climatology, atmospheric chemistry, etc. Other relevant data concern population density and distribution, traffic patterns, energy production and consumption patterns.

Step 2: Apportionment of ambient air quality to sources

The concentration of a certain pollutant measured at a receptor point is normally caused by a variety of different sources or source categories. It is essential to identify their relative contribution to air pollution at receptor points. For example, it is important to know for a certain receptor point within the area of concern the percentage of ambient SO_2 concentration contributed by power stations, heating devices for residential and commercial buildings, diesel engines, chemical and metallurgical processes or refineries.

Model calculations may assist the accomplishment of this task. Using the data of the projected emissions inventory, apportionment must also be done for the future.

The result of apportionment is a scale, which ranks sources and source categories with respect to their contribution to air pollution within the area. This scale gives an idea of the sources whose emissions reduction leads to the most effective reduction in air pollution.

Step 3: Identification of available control techniques

According to the scale mentioned before, for each source all available techniques to reduce emissions have to be identified.

Step 4: Integration of control techniques in alternative strategy plans

Available control techniques for the relevant sources have to be combined in a strategy plan. Normally several alternative strategy plans are possible, all capable of meeting the goals of the AQMS. Each alternative has specific characteristics with respect to time scale, costs, socio-economic consequences and interaction with other environmental media, which must be specified as precisely as possible.

Step 5: Selection of "best" plan

The above alternatives are the basis for the authority to select the "best" strategy plan. Which plan is considered "best" depends on the selection criteria applied by the authority. Important selection criteria normally are the time required to meet the AQMS goals, the costs and socio-economic consequences.

6.5 Surveillance

The establishment of emission standards as a part of the strategy plan requires the construction of a surveillance (monitoring) system to ensure compliance with standards. The same relates to ambient air quality (Fig. 5).

Source Monitoring

Source monitoring may be done continuously, periodically or on a random basis. The monitoring applied to a certain source or source category depends on the amount and the substances emitted and on the variation of emissions with time. Standard methods for measuring stack emissions should be established for the enforcement of emission standards. The AQMS should, therefore, adopt a common reference method beforehand and prevent the proliferation of other measuring techniques that invariably yield greatly different results. Technical research may later justify the acceptance of alternate instrumentation.

The AQMS should select one method for emissions measurement and use it as the single technique for enforcing the standards as in the past. Source sampling test methods have been extensively used to determine whether sources are in compliance with emission standards. This is far from ideal, since the intermittent nature of sampling reveals little about emission variations as a function of process changes.

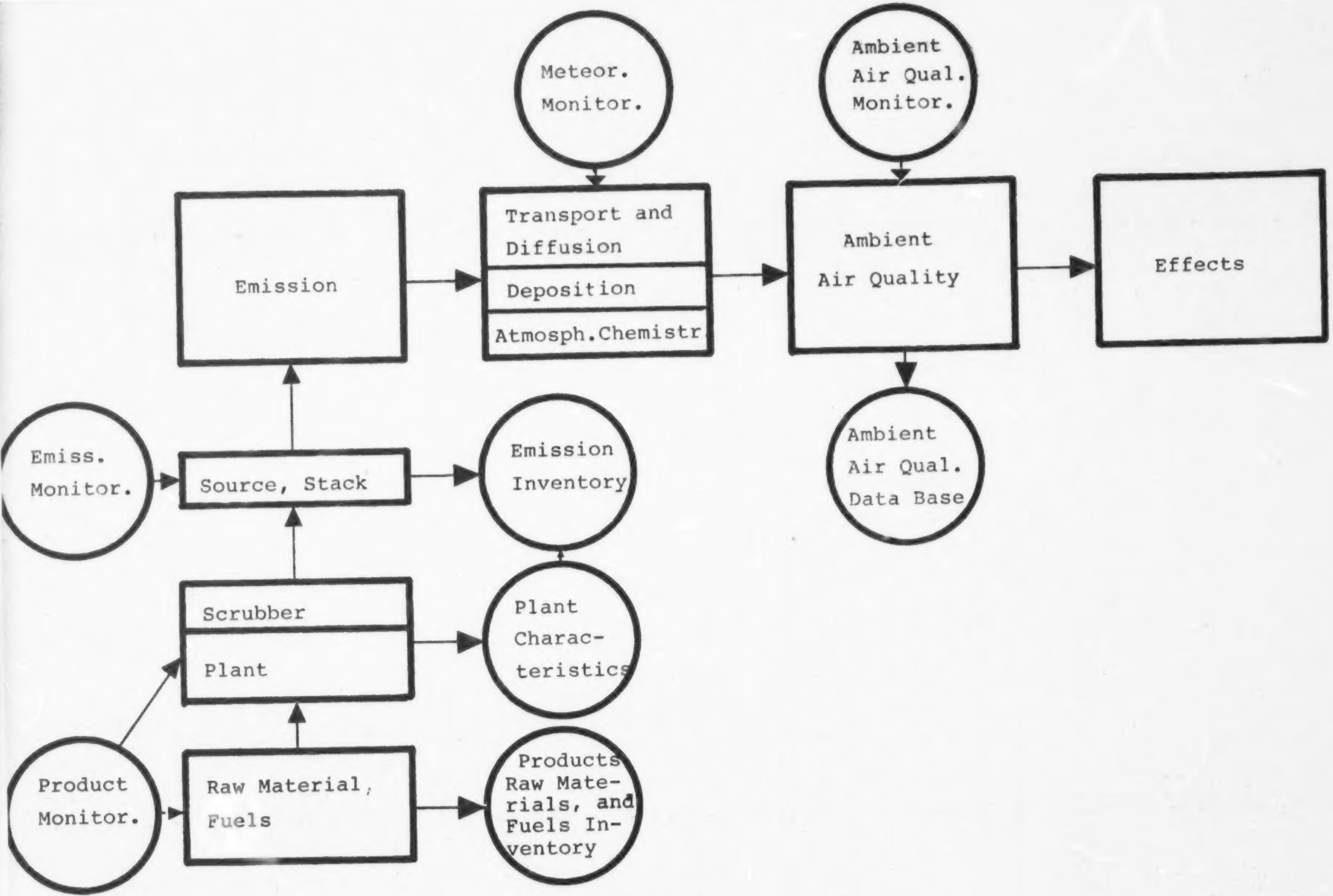
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Figure 5: Air Quality Management System

Continuous monitoring is most appropriate to survey the emissions of major sources, to survey plant operation, operation of gas cleaning devices and composition of fuels and raw materials. In cases where no continuous instrumentation is available, monitoring has to be done periodically or on a random basis with an appropriate sampling frequency, e.g. one sample per day. For monitoring of smaller stationary sources it will be sufficient to measure emissions periodically, e.g. once a year. Central heating burners and motor vehicles should also be included in this surveillance program because of the great number of these low level sources.

If source monitoring shows that emission standards are exceeded, appropriate emission reduction measures must be initiated immediately.

Data analysis and presentation must be closely related to the objectives of surveillance. This means that:

- data analysis has to produce the information which meets the specific information requirements of surveillance and

- data must be presented in a manner which is easily usable.

Most emission standards specify a single limit for emissions; those based on continuous monitoring will probably have a frequency distribution allowance similar to that used for ambient air standards. These data, in turn, lead the way to more advanced standards which will automatically allow for normal process variations yet enable the AQMS to continually oversee emission rates and take immediate corrective action when necessary.

The main objective of data analysis is to condense numerous measured values for a defined period to characteristic values which may be related to standards.

These characteristic values may be

- the maximum value,
- certain percentiles of the cumulative frequency distribution,
- the arithmetic mean value,
- the frequency of exceeding the standard.

Depending on standard definition, these values may represent concentrations or mass flow rates within a defined time period (e.g. kg SO_2 per hour).

Ambient Air Quality Monitoring

Often the measurement system used for the determination of the existing ambient air quality is also designated to perform the surveillance in the AQMS. One has to keep in mind, however, that in selecting a specific control strategy, once the existing conditions concerning sources, emissions and ambient air quality are known, the questions to be answered by the surveillance may not be adequately covered by the measurement system that was originally established. Unless an extensive, and often sophisticated measurement system was used from the start, this difficulty often occurs. At that stage in practice it is difficult to rearrange or extend the existing facilities because of the financial investments involved.

The surveillance can be continuous or periodical. It can serve different purposes, e.g. act as an early warning system to alert when high levels or standards are being approached or exceeded; determine the trend with time (from year to year); determine the transmission (transport, deposition, import and export from and to countries) or give a description of the geographical distribution and occurrance of the pollutants.

In most surveillance systems, especially the more detailed ones that also cover regional and local problem areas, mobile units are used in addition to the fixed reference measurement stations. The advantage of the mobile units is in this case that they can cover a large area within a relative short period of time. When compliance with ambient air quality standards has to be determined the representativeness of the measurements for a larger area has to be concidered. Any measuring equipment should be able to determine a level of a pollutant as specified by a standard or the criteria with an accuracy of at least ten percent of that level. An improvement can be gained when suitable remote sensing equipment is applied. With these instruments the space and time dependencies can be more adequately determined. Provisions have to be made within the AQMS that the surveillance system can be revised as soon as it becomes clear that it does not meet the objectives as laid down in the strategy plan.

Important points are the requirements for updating of the measurement equipment and for insuring that the measurement methods are equivalent and comparable to an acceptable reference procedure, for insuring that the equipment is properly maintained and for providing for training and operating technicians. In summary, there is a need for thoroughly planned and continuously operated quality assurance programs.

The data analysis and presentation methods to be used are, in most cases, comparable to the ones needed for the analysis of the existing ambient air quality. A difference, however, is the data presentation used to answer the specific question asked in the AQMS. Another problem is whether one should store and keep ready for retrieval the reduced data or the original measurement data. One has to keep in mind that for purposes other than the direct questions asked by the surveillance requirements, there may be a need for a renewed study or research based on the original measured data. Especially for trend analysis and studies concerning the transmission of air pollutants, it often becomes necessary, when new analytical techniques for data analysis become available, to formulate new criteria on which the data analysis should be based. In this case a new set of reduced data is required. For continuous measurements, one should aim to store only the validated measurement data if retrieval for future use is anticipated.

6.6 Interaction with other Environmental Media

The complexity of the problems involved in the protection of the environment from pollution should not be underestimated. Even the slightest pollution may lead - like all human activities - to changes in environmental systems. To understand these changes it is necessary to know the sources, concentrations, and properties of pollutants, the pathways they take through the environment and the nature of their interactions with other pollutants, receptors and sinks. At any stage or intersection in these pathways, pollution may have significant social, economic, ecological or toxicological implications for people and their life support systems. These implications will vary greatly according to the nature and source of the particular pollution process, the extent to which resulting pollutants are transformed at various stages in environmental pathways, and the sensitivity of the receptors. It is very difficult, therefore, to isolate particular pollution problems for meaningful control strategy. Consequently the environmental media (air, water and soil) should not be considered independently; they are linked together with many direct and indirect connections.

Air Quality Management Systems therefore can never be seen isolated from other environmental management programs. The programs for the protection of the other environmental media must be carefully balanced with the air pollution strategy plan to ensure that an improvement in air quality will not lead to deterioration in other media.

Examples of the direct interaction of air pollutants with other media are:

- sulphur dioxide and nitrogen oxides can be absorbed in atmospheric water droplets and cause increased acidity of rain (and therefore in the soil) in nearby and remote areas,
- power stations need direct cooling water systems or cooling towers and the waste heat will either be released into rivers or into the atmosphere,
- certain heavy metals may affect vegetation, thus introducing them into the food chain,
- the emissions of dust mostly from coal fired furnaces or metallurgical plants which contain certain heavy metals, lead to sedimentation of dust containing these heavy metals.

One example of indirect interaction (caused by air pollution abatement measures) is:

- gas cleaning devices very often use wet scrubbing systems to absorb emitted substances; the scrubbing water will sometimes be released into rivers and the pollutants may be introduced into the food chain; similar problems may arise if the precipitated substances or their reaction products are deposited.

Air pollutants and their reaction products have different fates after they have been released into the atmosphere.

By the emission of pollutants into the air the natural composition of the atmosphere may be changed. It has been pointed out that there might be a danger of inadvertent modification of the climate, both in terms of direct impact on man and the biosphere and of the hard choices that countries might need to face to prevent such impacts. Air Quality Management Systems therefore should include possible climatic modifications into their considerations. Examples of these interactions are:

- some reactive hydrocarbons form together with nitrogen oxides, under the influence of sunlight by physical-chemical transformation in the atmosphere, the different products of photochemical smog,
- the concentration of carbon dioxide in the atmosphere has increased in the last century from about 280 to 330 ppm,
- depletion of the ozone layer.

6.7 Revision of Strategy Plans

Normally a plan will not work from the beginning to the end without any revision. It is therefore necessary to check its success and to keep it oriented towards the original or revised objectives. Because a strategy plan is designed for a time scale of about 10 or 20 years, a revision of strategy plans must be an essential part of AQMS. In general, revision is necessary, if the plan is inadequate to attain or maintain the adopted standards or objectives.

Also, a review of the plan for possible revision should be made after fixed periods, e.g. after every 3 to 5 years. These reviews will guarantee that assumptions and boundary conditions made in plan design are checked and kept up to date. Independent of these periodic reviews the plan must be revised if something essential happens to affect the plan or its objectives. Plan revision is necessary, if:

- the legal basis for air pollution control has changed,
- new emission, product or air quality standards are set,
- substantial changes take place in the emissions,
- new scientific findings about nature and extent of effects are available,
- new control technology becomes available,
- an unexpected long term shortage of a certain fuel occurs,
- a new energy supply system is established, e.g. using the waste heat of a large power plant for space heating.

7. SUMMARY

This guideline document and its appendices may assist countries with current and projected air pollution problems in developing a systematic and effective Air Quality Management System (AQMS).

It is addressed to national, regional and local authorities concerned with the establishment and operation of an AQMS, and it should be used by the management of one of these authorities.

The document gives an overview of several AQMS and the applied practice in NATO countries. It describes the AQMS building blocks - assessment, standards and criteria, strategy plans - as well as the technical and economical requirements and their legal and administrative implications.

Emphasis is put on the formulation of strategy plans. Major strategy plan options, criteria for the selection of control strategies, surveillance technique, possible interactions with other environmental media and also the necessity for revision of strategy plans are described.

ANNEX I

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ANNEX II

NATO/CCMS Documents on the First Air Pollution Pilot Study (available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

AIR POLLUTION (No. 5)

Proceedings of the 2nd Meeting of the Expert Panel on Air Pollution Modeling, (26 - 27 July 1971, Paris, France). Out of stock

AIR POLLUTION (No. 6)

Guidelines to Assessment of Air Quality (Revised)

APPENDIX A	Assessment of Air Quality in Ankara (February 1973)
APPENDIX B	Assessment of Air Quality in St. Louis (February 1973)
APPENDIX C	Assessment of Air Quality in Frankfurt (June 1974)
APPENDIX D	Assessment of Air Quality in Oslo (February 1973)
APPENDIX E	Assessment of Air Quality in the South Holland Region (December 1973)

AIR POLLUTION (No. 7)

Quality Criteria for Sulphur Oxides (November 1971). Out of stock

AIR POLLUTION (No. 8)

Air Quality Criteria for Particulate Matter (November 1971). Out of stock

AIR POLLUTION (No. 10)

Air Quality Criteria for Carbon Monoxide (June 1972)

AIR POLLUTION (No. 12)

Control Techniques for Sulphur Oxide Air Pollutants (October 1973)

AIR POLLUTION (No. 13)

Control Techniques for Particulate Air Pollutants
(October 1973)

AIR POLLUTION (No. 14)

Proceedings of the 3rd Meeting of the Expert Panel on Air Pollution Modeling
(2 - 3 October, 1972, Paris)

AIR POLLUTION (No. 15)

Air Quality Criteria for Nitrogen Oxides (June 1973)

AIR POLLUTION (No. 18)

Control Techniques for Carbon Monoxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 19)

Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 20)

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 29)

Air Quality Criteria for Photochemical Oxidants and Related Hydrocarbons (February 1974)

AIR POLLUTION (No. 30)

Proceedings of the 4th Meeting of the Expert Panel on Air Pollution Modeling, (28 - 30 May 1973, Oberursel, Germany)

AIR POLLUTION (No. 33)

Final Report (May 1974)

AIR POLLUTION (No. 35)

Proceedings of the 5th Meeting of the Expert Panel on Air Pollution Modeling (4 - 6 June 1974, Roskilde, Denmark)

AIR POLLUTION (No. 41)

First Follow-up Report (December 1975)

AIR POLLUTION (No. 50)

Second Follow-up Report (December 1976)

AIR POLLUTION (No. 67)

Third Follow-up Report (November 1977)

AIR POLLUTION (No. 96)

Fourth Follow-up Report (October 1978)

AIR POLLUTION (No. 6, Appendix C revised)

Assessment of Air Quality in Frankfurt (December 1977)

ANNEX III

NATO/CCMS Documents on the Pilot Study on Air Pollution Assessment Methodology and Modeling
(available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

Air Pollution (No. 42)

Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application
(24 - 26 September 1975, Frankfurt/Main, Germany)

Air Pollution (No. 51)

Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application
(7 - 10 September 1976, Airlie House, USA)

Air Pollution (No. 70)

Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models) (October 1977)

Air Pollution (No. 71)

Air Quality Management Systems (AQMS) (October 1977)

Air Pollution (No. 88)

Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques) (October 1978)

Air Pollution (No. 89)

Glossary of Terms Generally Used in Air Pollution Assessment Methodology and Modeling (October 1978)

Air Pollution (No. 80)

Proceedings of the 8th International Technical Meeting on Air Pollution Modeling and its Application
(20 - 23 September 1977, Louvain-la-Neuve, Belgium)

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Appendix A Air Pollution Emissions Inventory Systems

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1. Introduction

Many activities within an air quality management system require the use and assessment of various types of air pollution data. Data on air pollutant emissions and air quality data are the most important of these data types. An emissions inventory system supports pollution assessment activities by collecting, screening, storing, and presenting emissions data in a systematic and useful manner. The purpose of this appendix is to describe how an emissions inventory system should be organized and operated. This appendix includes the central part of NATO/CCMS Doc. No. 104, which also presents a number of technical papers on emissions inventory systems used in Belgium, Canada, the Federal Republic of Germany, the Netherlands, Norway and the United States of America.

2. Purpose and Scope of an Emissions Inventory

2.1 Definition

An emissions inventory is a set of information on sources and emissions of air pollutants in a given area. Both man-made and natural emissions may be included. Data is generally categorized in some detail by type of pollutant, source type or category and source location. Emissions estimates or projections are usually made for specific time periods. Thus, an emissions inventory provides a more or less detailed description of the air pollutant emissions within a specific area or region.

An emissions inventory system is the method by which an emissions inventory is compiled and maintained. Generally, this will include collection, screening and refining, storage, and summary and retrieval of data related to emissions.

2.2 Objectives

The contents of an emissions inventory and the elements of the emissions inventory system are determined by the use that will be made of the data. For this reason, the objectives of an emissions inventory system within the air quality management system (AQMS) should be carefully evaluated as the first step in developing the emissions inventory system. Such objectives may be, for example:

- the assessment of the current emissions situation in a certain area, such as determining the contribution from the various emitter categories
- the prediction of changes in the emissions situation due to the addition of new air pollution sources
- the prediction of changes in the emissions situation due to certain control strategies
- the prediction of changes in the ambient air quality from the above-mentioned changes in the emissions situation
- the development of abatement and control procedures
- design and management of air quality monitoring networks

For most of these applications, information is required on the type of pollutants, the mass flow rate of the emissions, the cause and location of the emissions, and the times at which they take place. Data on the emitters may also be included.

The objectives of the emissions inventory will also determine the amount of detail required (resolution). A comprehensive emissions inventory may, for instance, include detailed information on industrial installations, their mode of operation, their exact geographic location and the time when the emissions take place. Less detailed inventories may deal only with total emissions in certain regions, presented as yearly averages.

Finally, the use of the data determines the required accuracy with which the data should represent the current emissions situation and, thus, also dictates the frequency of updating of the emissions inventory.

2.3 Costs

Since the objectives of an emissions inventory determine the contents of the data bank, the degree of detail in the data, and the accuracy of the data, they also will determine the costs of establishing and maintaining the inventory. Prior to the development of an emissions inventory, these anticipated costs should be carefully evaluated. Not only should the costs associated with the first round of collection, storage, and processing of data be considered, but also those associated with the updating and maintenance of the system.

2.4 Relation to other Data Banks

In some cases, an air pollution emissions inventory is combined or coordinated with inventories of other emissions, such as those causing water, waste, and noise pollution. (See, for example, the Dutch and Norwegian technical papers in NATO/CCMS Doc. No. 104.) It may then be useful to consider the particular aspects of these additional forms of pollution, along with those of air pollution. If feasible, it may even be advantageous to consider one system containing all desired types of emissions information or, at a minimum, a set of compatible systems.

Existing statistical data banks (e. g., data on industry, transportation, population, energy consumption, meteorology, etc.) may be particularly useful in providing such data to an air pollution emissions inventory. Provisions for an easy flow of such data into the emissions inventory would then be required.

3. Principles

3.1 Elements of Emissions Inventory Systems

The establishment and development of an emissions inventory system requires an effective coordination of the following elements:

- data collecting
- data refining
- data processing (storage and availability)
- data evaluation (retrieval and summary)

When this coordination is reached, the emissions inventory can serve as a valuable tool in air pollution management.

3.1.1 Data Collecting

When collecting data, all causes of emissions fall into one of the following emitter categories:

- major industrial facilities*
- small industrial facilities
- domestic consumers
- transportation
- natural causes

Within the above-mentioned emitter categories, different procedures of data collection may be applied or combined. These include:

- using emission factors
- using questionnaire forms
- performing source testing and/or other special studies

In data collecting, two approaches may be used: the individual approach as described in 4.1.2 and the collective approach as presented in 4.1.3.

Sources may be grouped into three types: line, point, and area. Major industrial facilities are often dealt with as point sources. Line sources usually pertain to traffic emissions, while area sources encompass emissions from domestic consumers or smaller industries. However, all three types of sources may be used in describing the emissions of industrial facilities:

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* In this context, "industrial facilities" also includes agriculture, mercantile trade, services, etc.

- point sources correspond to well-defined outlets such as stacks
- line sources may correspond, for example, to roof outlets or a number of small point sources arranged in a line
- area sources may encompass smaller sources distributed over a large plant area (e. g., leakages, emissions from storage tank fields, and small point sources)

The concept of area sources also may be used to group together all emissions within an area without distinguishing between the different emitter categories listed above.

The collection of data varies from one country to another, and the reader is directed to the various technical papers contained in NATO/CCMS Doc. No. 104 to obtain further details. There is, however, one basic difference in the approach used by European countries as opposed to that used by North American countries. In Europe, most emissions inventories have been carried out over a limited area, but very comprehensively, whereas North American inventories have been conducted nationwide. The difference in approach stems from a differnce in objectives.

3.1.2 Data Refining

In the context of an emissions inventory system, data verification and data auditing procedures are absolutely necessary. This applies whether the emissions data are evaluated manually or by computers. It can be done directly after data collection, after data storage, or with data summaries, in manual or computerized form. Additional information on data refining is presented in 4.2.1.

3.1.3 Data Storage and Availability

As an emissions inventory is a systematic collection of a large amount of detailed data, it is necessary to have a system that allows effective processing, storage, and retrieval of the data.

The decision to use computers or to employ a manual approach for the emissions data processing system is important. The procedures and the medium of data storage should be developed after a thorough evaluation of the expected volume of data and frequency and types of uses and updates. Obviously, a small data base which essentially will never be updated or updated infrequently is most appropriately stored manually (e. g., on the original data forms or on coded cards). Manual data storage also may be cost-effective for large data bases which will seldom be changed.

If there is a large set of data requiring frequent modification and sophisticated summarization and retrieval, automatic data processing is necessary. It should be noted, however, that once the file format has been selected and the computer software developed, it is very costly and time-consuming to make essential changes.

If time or cost constraints dictate incremental development of the inventory, such as starting with an inventory for one pollutant or for pollutants from one type of plant (e. g. combustion for heating purposes), the medium of data storage should be decided upon with respect to the overall goals of the AQMS and the desired future form of the emissions inventory. Therefore, if a comprehensive, regularly updated emissions inventory is to be a part of the AQMS, consideration of data processing by computers at the onset is recommended.

Experiences gained in Canada in establishing a computerized emissions inventory system from a manual system are of interest. A summary of this approach is described in Paragraph 6.2.

3.1.4 Data Retrieval and Summary

A main objective of an emissions inventory system is to provide the users with pertinent and timely information. To achieve this, the system must be designed by first defining user requirements, and then identifying the data needed to parovide this information and the retrieval and summary capability necessary to produce desired data in a timely and useful manner.

A manually-based emissions inventory has only limited possibilities of providing the user with summaries and various retrieval scenarios. A computerized emissions inventory system, on the other hand, allows a multitude of summaries and retrievals. Data can be retrieved from a system according to various basic arrangements such as:

- emissions according to source category
- emissions according to pollutants
- emissions within a specific geographical region

Any of these groupings can be used by itself or in combination to display emissions data. Summaries and evaluations of emissions data can be performed via selections according to a number of codes, such as the following examples used by the Federal Republic of Germany and/or the United States of America:

- source classification code
- source code
- estimating method code
- pollutant code
- computed emissions
- control equipment code
- control efficiency code
- gas cleaning unit code
- operating rate
- location coordinates
- sulphur content of fuel
- source height
- emission rate

Evaluations using combinations of above mentioned codes then may include, for instance:

- emission tabulation by source category, plant, region, etc.
- contributions of specific sources to emission totals
- emission density maps for stationary and mobile sources
- emission arranged by pollutant
- time fluctuation of emissions
- evaluation of changes in control equipment or fuels

The emissions inventory data systems of the United States and Germany serve as bases for demonstrating evaluation possibilities. Comprehensive data banks developed from the above mentioned systems include those of Canada (developed from the United States' system) and the Netherlands and Belgium (developed from the German system).

3.1.5 Updating

The purpose of pollutant emissions inventory is best served when the inventory is up-to-date. The emissions inventory system should, therefore, include procedures for the submission of data to the responsible organization, as well as for collection or development and entry of data by that organization.

3.2 Resolution of Information

Emissions inventory systems can be developed to many different degrees of detail or resolution. The Norwegian example of a sulfur dioxide (SO_2) emissions inventory of the entire country has low resolution with regard to space. Similar inventories have been developed in other countries and states. A highly detailed resolution should be sought for emissions inventories to be used for planning purposes, while more aggregated inventories may be sufficient for other purposes.

3.2.1 Criteria for Resolution

The future uses of an emissions inventory system within an AQMS define the types and degrees of resolution necessary in the inventory. Listed below are four examples of uses of an emissions inventory with distinctly different requirements as to resolution of space, time, pollutants, and sources.

(1) A general collection of emissions information to be used in explaining measured air quality

(2) A base of emissions data for land use, urban, and regional planning

(3) A file of information relevant to plant licensing, for licensing authorities

(4) A compilation of data related to air pollution control plans or strategies

3.2.2 Spatial Resolution

For only a general description of emissions, spatial resolution need not be very great. For example, information may only be required at the regional level. An emission inventory for SO_2 in Norway has a grid size of 55 km x 55 km and a German SO_2 and dust inventory has a grid size of 70 km x 70 km. Such systems may provide emissions estimates only for these relatively large areas, and a resolution of several kilometers may be sufficient.

For land use, urban, or regional planning, for plant licensing or for air pollution control planning, the spatial resolution required depends on the size of the country or other area covered and on the distribution of emission sources and receptors (e. g. residential areas). Less resolution will be required where sources and receptors are far apart or restricted to specific areas; higher resolution is necessary where development is more concentrated and there is more mixing of sources and receptors. The American emission inventory system allows entry of coordinates with a resolution of 100 meters; the Dutch system specifies locations to 10 meters and the German system allows for a resolution as fine as 1 meter.

3.2.3 Temporal Resolution

Time spans used in the emissions inventory system may be predetermined (e. g., seasonal, daily, hourly) or may vary as a function of the activity being inventoried. The operation of the activity, the production cycle and/or its emission or production instrumentation may determine the temporal resolution permissible or required.

Minimal resolution with respect to time might include seasonal variations in emission rates, such as that used in the emission inventory for Norway. Emission data to be used for land use planning should be coordinated with the various ambient air quality standards on which the AQMS is based. For example, the United States has standards with averaging periods from 1 hour to 1 year, while Germany's standards are based on measurements with an averaging period of half an hour.

Emissions data must be of fine resolution to be used in plant licensing. Systems used in Belgium, Canada, Germany, Norway, Netherlands and the United States allow resolution to 1-hour periods. It is generally necessary to define actual emissions and the times in which they occur (e. g. hours/day, days/week and weeks or months per year).

Emissions information to be used in dispersion modeling should include the time of day or night and seasonal fluctuations, due to the necessity to coordinate with meteorological phenomena which may vary significantly from day to night or season to season. For example, emissions from traffic follow very distinct daily and seasonal cycles. Resolution of emissions on a daily and seasonal basis will generally be sufficient for air quality control planning and development of control strategies.

3.2.4 Pollutants Inventoried

In all emissions inventories, a distinction must be made between the principal air pollutants of concern. Generally, SO_2, oxides of nitrogen (NO_X), carbon monoxide (CO), hydrocarbons, and particulates are included. While other pollutants may be important, inclusion of them in a general emissions inventory (e. g. regional-scale resolution) may not be advisable due to distortion which would occur in averaging over an extensive area.

Consideration of specific hazardous pollutants (e. g. asbestos, fluorides, vinyl chloride) is important in land use planning. Equally high resolution is required in an emissions inventory to be used in licensing in order to allow full comparison of existing and proposed facilities.

Air quality control planning also requires full detail on the various pollutants emitted by industrial facilities, as the amount of specific pollutants emitted is a basic piece of data needed in investigating and executing control plans.

The completeness of the emissions inventory may be influenced by spatial resolution and temporal resolution permissible, the use to be made of the emissions inventory, and the resources available. For example, the system may inventory one pollutant in great detail, a few pollutants, many pollutants, or attempt an inventory of all pollutants.

3.2.5 Resolution of Source of Emissions

Depending on the purposes of the emissions inventory, considerable variation in the resolution of actual emission sources is possible. If for a certain region just a general emissions picture is needed and the total emission can easily be estimated, an identification of individual sources is not needed.

For the purposes of land use, urban, and regional planning, resolution of emission sources to the level of individual industrial plants, roads, and other specific point, line, or area sources will probably be necessary.

Additional detail to the level of industrial processes and operations which cause the air pollution will be necessary in emissions inventories to be used for licensing or for air quality control planning.

4. Methods

4.1 Data Collection

The compilation of a detailed and useful inventory of air pollutant emissions requires the collection of a substantial amount of accurate and up-to-date technical data.

Source data are necessary to properly identify sources and to calculate emissions, determine compliance status, or support models for predicting air quality. These source data requirements may include source description and details concerning the nature, extent, space and temporal distribution of emissions and exhaust conditions. For inventories related to air quality modeling or short-term air quality standards, the recording of time-dependent emissions may include not only annual averages but emissions for individual seasons, months, days, hours, or even in special cases (e. g. flare emissions) parts of an hour.

When the type and magnitude of the emissions are already known, the emissions inventory procedure can consist of the systematic collection and ordering of information already known or available from questionnaires or interviews. Measured source emissions, based on source test results, should be included whenever practical considering both accuracy and cost. The larger number of sources and the diversity of causes of emissions usually make detailed measurement of emissions on a source-by-source basis impractical. If direct measurements or estimations for certain sources or substances are not practical, emission factors should be applied.

The two approaches used to obtain the data required are: (1) the collection of detailed data on individual emission sources through questionnaires and/or interviews, which is termed the individual approach, and (2) the estimation of emissions based mainly on statistical information, termed the collective approach.

The collective approach is used more often to investigate a large number of similar emitters whereas the individual approach is used for individual emitters.

4.1.1 Calculation of Emissions using Emission Factors

An emission factor is an expression of the rate at which a pollutant is generated as a result of some activity, divided by the level of that activity. The emission factor thus relates the quantity of pollutant emitted to some indicator, such as production capacity, rate of raw material usage, or quantity of fuel burned. For example, the emission of CO from a steel-making process is expressed as the number of kilograms of CO emitted per ton of steel manufactured. Another example is the emission of SO_2 from fuel conbustion, which can be calculated from the sulfur content of the fuel.

Emission factors are not only applicable to the collective approach, but may also be useful for the individual approach to data collection. This is because of the greater uncertainties of one single source test result in comparison to emission factors derived from a few or many similar test results, since one measurement and its test result can only be related to the actual source conditions at the time of the test.

Some countries (e. g., the United States) publish documents containing emission factors, compiled from source tests, material balance studies, and engineering estimates for the major causes of air pollution. Many of these pollution causes are found in other countries and these factors may sometimes apply directly. In other cases, it may be possible, with some critical review, to adapt these factors to local problems. Whenever feasible, however, it is recommended that representative emission factors be developed through tests conducted at the processes which are major causes of pollution within each country.

The accuracy of an emission factor is most directly related to the number of studies performed on the particular sources and/or causes. In general, the most intensive efforts are usually concentrated on the major causes of air pollution and on the most common pollutants. Tests need not be performed at each facility when these facilities use similar processes. One or two representative sources can be surveyed to allow the development of reliable emission factors, which are then applied to the other facilities with similar processes, taking into account any peculiarities.

There are limitations to the applicability of emission factors. In general, emission factors are not precise indicators of emissions from a single source, but are most valid when applied to a large number of sources and causes. When such limitations are taken into account, emission factors can be extremely useful in establishing emission inventories.

There are two general means of calculating emission factors: uncontrolled (as in use in the USA) and controlled or actual (as used by the FRG). A controlled emission factor, in contrast to an uncontrolled emission factor, includes the efficiency of the applied cleaning device. Both approaches are equally valid.

4.1.2 Individual Approach

The first step of an individual approach towards developing an emissions inventory from a certain class of facilities is a literature review which will isolate information regarding the characteristics of the likely causes of relevant pollutant emissions. Questionnaires are then prepared for completion by company representatives or by the control agency through interviews and plant visits.

It may be possible, or even preferable, to design a general questionnaire applicable to any type of plant, facility, or apparatus. Although this may preclude obtaining very detailed information, it can be quite suitable for the purposes of the emissions inventory.

In any case, questionnaires to be completed by company representatives should be as brief and clear as possible to minimize the burden on the respondent. Therefore, simple questionnaires for special types of causes may be more desirable than a general type of questionnaire applicable for a broad variety of equipment or facilities.

As a questionnaire is an optimal means of collecting useful data, it should be carefully designed as to format and presentation with the aid of a questionnaire design specialist. A computer data specialist should also be involved in designing questionnaires, to prepare them for computer entry of collected data. Examples of questionnaires can be found in NATO/CCMS Doc. No. 104.

Essential queries included in any questionnaire concern the geographic location of the facility and all information related to its identification and definition (e. g. plant name, address, responsible person to contact, and materials processed or used). Other information solicited through the questionnaire may include: the content of all components of the raw materials and end products, the flow of the components of interest through each process stage, the actual and potential emission causes in the plant, all stack data, the existing and planned control measures, the mechanical characteristics of control equipment, the physical and chemical properties of the emissions, the method of estimation of emissions and the plant operating and production schedule.

The data collected through the questionnaire approach are first examined for completeness, logic, and accuracy. The data are then processed and classified systematically according to type of emission source and geographic location. Available emission factors obtained from the literature can be used for comparison purposes. By using a computerized system, part of the analysis concerning completeness, logic, and accuracy can be carried out while processing the data (4.2.1).

An individual approach to emissions estimation is strongly recommended for power stations, solid waste and municipal incinerators, and other industrial process plants such as:

- iron and steel-making plants
- primary aluminum, copper and nickel, lead and zinc smelters
- cement works
- stone quarrying and processing plants
- kraft pulping and sulfite pulping plants
- fertilizer manufacturing plants
- petroleum refineries and petrochemical plants
- sulfuric acid manufacturing plants

Criteria to indicate which plants or facilities are to be evaluated by the individual approach can, for example, be based on the number of employees, production levels, or the quantity of contaminants emitted. An individual approach is not recommended for smaller sources such as dry cleaning plants, and space and office heating systems.

To obtain accurate and useful data, cooperation with industry is essential. Therefore, industrial associations should be contacted and their support obtained prior to collecting information from individual industries.

Once the purpose of the inventory and the manner in which it will be conducted are explained, industry usually is cooperative in finding and reporting the required data. Industry's major concern often lies in the confidentiality of some of the information to be provided. Consequently, the greatest caution must be observed with regard to publication of inventory results so as make it impossible to deduce the confidential emissions data or other data (e. g. production or process information for individual emitters). Some countries, however, do not regard emissions data on a plant-by-plant basis as being of a confidential nature.

Because an emissions inventory is more useful when the information it contains is up-to-date, procedures should be established for the regular submission of data to the responsible organization. These methods may include (1) regular reporting of significant changes in emissions, (2) reporting only upon special occasions such as changes in legislation or in the purpose of the emission inventory, (3) a registration system requiring reporting of installation or alteration of production or air pollution control equipment, and/or (4) a licensing procedure allowing inventory updating when a license is issued for operation of a new or modified plant or emitter.

4.1.3 Collective Approach

In situations where information needed to estimate emissions on a facility-by-facility basis is lacking, or where it is felt to be unnecessary or not feasible, it is possible to estimate emissions using emission factors, statistical information, and other available data. The collective approach differs from the individual approach in that the former is more suited to the analysis of a number of emitters grouped together than it is to specific emitters. Classes of emitters which cannot be evaluated by means of the individual approach include motor vehicles, railroads, marine vessels, aircraft, residential fuel combustion, forest and field fires and also various types of minor industry (e. g. dry cleaning plants, greenhouses, gasoline filling stations).

Information regarding industrial production and fuel consumption, which is required to estimate emissions from some of these causes, can often be obtained from government departments responsible for collecting these statistical data. This can be supplemented by data published by industrial associations, and by information available from other government departments and agencies. Other requirements are data on population, number of dwellings, number of employees, and land use, etc. These types of information are generally available from census or planning organizations.

Several options exist to estimate emissions from residential heating processes by a collective approach. One option, which may be used to obtain a large scale emission value, is based on total fuel consumption in an area and corresponding emission factors. A more detailed method is based on fuel consumption, population density, and fuel-dependent emission factors. Another detailed procedure involves counting space heating installations and classifying them by type and size. With these data and fuel-dependent emission factors, the emissions of primary pollutants can be calculated for small areas. In nearly all cases, seasonal and even daily variations in temperature and resulting emissions can be taken into account.

Updating procedures may take the form of keeping abreast of revisions or new compilations of any information used in the creation of the emissions inventory, including new census or other government-collected statistics, new land use plans, and new or revised technical information such as emission factors. Changes in the emitters themselves (new industrial facilities or processes, alteration or termination of existing operations, etc.) must also be followed and reflected in updates of the emissions inventory. This last type of information can be obtained from an authority involved in air pollution control permits and registration, or by various reporting requirements.

4.2 Data Processing

The purpose of any data handling system is to provide a mechanism whereby large sets of data can be easily and efficiently stored and then retrieved as desired. The final test is whether the system provides the desired information to the user in a short time. If a data handling system is designed by using the actual requirement for information to identify the data needed, the requirements of the total system will be understood and the system will meet the expectations of its users.

A basic decision associated with the emissions data processing system is whether or not to use computers. This decision will impact upon every aspect of the system-design time, implementation, cost and maintenance, as well as the operating capabilities of the completed system. Because of its importance to the total inventory system, the decision to create either a manual or computerized system should be made after careful consideration of:

- the volume of data to be stored
- the frequency, size and variety of data or summary retrievals
- the frequency and size of updates, and the availability of resources (information and capital)

Information resources may include storage systems with meteorological data, compilations of emission factors, statistical data concerning automobile density, space heating distributions, etc. A computerized system can be designed to transform these distributions or other statistics, through use of emission factors, into emission and source data.

In situations where it is advantageous to establish an emissions inventory in stepwise or incremental fashion, because of time and/or cost considerations, it is imperative to establish a comprehensive data processing system. Incomplete or overly simplified information can be easily introduced into a comprehensive system; expansion of a severely limited system to one of a comprehensive nature can be very costly as well as time-consuming. One example of an incremental emissions inventory would be an SO_2 emissions inventory from fuel combustion which is later expanded to include SO_2 emissions from other emitters, such as copper smelters.

If computer processing is used, computer specialists and systems analysts for data collection and evaluation should be included in the analysis team. These specialists can assure that the computer system will be responsive to the requirements of the user community.

Regardless of the type of data processing system chosen, a number of factors must be considered in developing a comprehensive system. Due to the diversity of situations for which emission data can be collected and analyzed, these considerations are discussed below in a general context.

4.2.1 Data Auditing

In the context of a total system, computerized or manual, data auditing procedures are responsible for verification of data on input, after they are stored, or in response to inquiries concerning missing or updated data. Data auditing must provide a mechanism for each of these situations, particularly in reference to user inquiries. The purpose of the data auditing procedures is to assure the accuracy and completeness of the emissions data. The following describes various steps of data auditing:

4.2.1.1 Checks of Data during Input

Whenever data are submitted to manual or computerized systems, the input must be checked for format and completeness before it is stored in the system. If the submitted data are in the wrong format, incomplete, in error, or unusable for some other reason, they should be rejected. Rejected data should not be stored in the emissions system as the data would be inaccurate and inappropriate for any further summary or retrieval. This procedure can be used as a formal check with regard to required data reporting.

Once data have passed the formal check and it has therefore been determined that the data are useful and complete, the data are ready to be validated. This procedure incorporates additional checks to determine whether the data submitted reflect a true or realistic situation. These procedures may use high value or reasonable range checks and are essential in determining whether the data are within an expected range and do not indicate some improbable or unrealistic condition. Since this validation check is more subjective than the formal check, data failing the validation check may or may not routinely be stored on the system depending on how useful the data may be for retrieval or analysis. If data failing a validation check are stored, the data should be investigated in some manner to ensure correctness.

4.2.1.2 Checks After Storage

Another auditing procedure consists of reviewing a block of data already stored to ensure that they still reflect the true condition of the emitters. This procedure is used as necessary and is performed by individuals with sufficient background and authority to review the data. This type of check can be seen as a certification.

4.2.1.3 Checks in Response to Inquiries

On occasion, questions as to the correctness of data are raised by data users. For these situations, a procedure should be instituted whereby questions are referred to a knowledgable institution for resolution. Based on the response, appropriate data are updated.

When questions arise regarding the inclusion of additional information not already contained within the system, a verification procedure is initiated. This may result either from questions raised by data users or through independent crosschecking of data records. New data may also be added to the system in the case of new emitters or existing emitters which have inadvertently been left out of the system.

4.2.2 Data Storage

The concepts of computerized emissions data systems vary slightly among the various countries. A subgrouping of information into files assists retrieval of data. The concepts of the Federal Republic of Germany and the United States are described below as examples.

German emissions inventory data files:

- operator identification file - all information on location and nature of plants causing possible environmental pollution

- source identification file - all information on source, nature, size, and location of transition points of air pollutants into the atmosphere

- facility file - all information on nature, capacity, location, and materials processed in the facility
- emissions file - all information on nature, amount, duration, and frequency of emissions including control equipment
- pollutant identification file - information on air pollutants and materials processed or used

The United States emission inventory system:

Data files:

- point source file - all source information on each emitter, including federal facilities
- area source file - all source information on each area (county) emitter
- hazardous pollutants source file - information on each emitter of hazardous or potentially hazardous trace substances
- emission factor file - changes can be made without modifications of other files

Identification files:

- geographical identification file - all federal regional offices, state, Air Quality Control Region (AQCR), and county names and identification numbers
- control equipment identification file - all control equipment names and identification numbers

- process identification file - all process identification numbers as required for the inventory to be used in special modeling programs

The aforementioned files are the main information resources within these emissions inventory systems. Together with auxiliary files and additional information (e.g., air quality data, population data, meteorological data, and industrial fuel usage data), they should form a comprehensive data bank available for the AQMS.

Coding forms for input into the emissions inventories cited above are given in the appended national papers. These forms show in detail which data are be stored.

Similar comprehensive data are contained in the Canadian, Dutch and Belgian systems. These files and forms generally have been derived from the United States and German systems.

4.2.3 Data Retrieval

Data retrieval procedures are the ultimate test of the total emissions inventory system. If accurate, adequate, and timely retrievals can be made from the system to the satisfaction of the users, the emissions inventory system is a successful and well-defined tool. Very few systems are totally successful according to these criteria, but the correlation of the retrievals to the desires of the user community is nonetheless a good measure of the success of a system.

Both raw data and summary information will be candidates for retrieval. Depending on the anticipated ratio of summary retrievals to raw data retrievals, the system may be designed to maintain summary information already calculated for quick retrieval. This summary information may be in the form of reports or publications available on a shelf in the case of manual or computerized systems. With the computer system, data summaries also may be stored on computerized files which allow for updating each time the raw data are updated.

Simple examples for retrieval are:

- Emission report. This report outputs, for a specific geographical area, emissions of each of the criteria pollutants associated with all the sources represented, as well as the total emissions for all sources.
- Plants emission report. This report presents a listing of the names of plants and the emissions of every pollutant associated with each plant.

Some special retrievals from an emissions inventory data bank may serve for demonstration purposes (Cologne Emission Inventory):

- The evaluation of industrial emissions with regard to the release height showed that:
    1) about 85 percent of the hydrocarbons is released at heights below 20 meters
    2) about 70 percent of all dust is emitted at a height of 60 to 100 meters
- A retrieval concerning different industrial sources showed that only 60 percent of all hydrocarbons is released via defined sources

- Looking at emissions from different facilities or installations, it was found that 50 percent of chlorinated hydrocarbons was emitted from reprocessing plants, about 25 percent was due to chemical processing plants and another 25 percent from surface coating installations or other emitters.

Retrievals from large data sets can be performed via selecting codes (3.1.4). A small number of selecting codes will yield comprehensive detailed cutput data. A large number of selecting codes (strongest restrictions) will yield only few data with very specific information content.

One consideration unique to emissions data is the disposition of confidential data. Some policy will be necessary to recognize data as confidential or not. If data are confidential, the retrieval procedures must recognize this status and prevent these data from being available to unauthorized personnel.

4.2.4 Data Summaries

A summary of data is generally used either to check data for completeness or to obtain information on emission totals. Data summary procedures should be developed early in the design of any emissions inventory system. Decisions concerning the type of data summaries or analyses required will, in turn, indicate the raw data to be collected. Each item of data collected should have a definite purpose, as an identifier or data value, or in the calculation of summaries.

Since summaries are at least one level removed from the raw data, procedures previously described under data auditing (4.2.1) must assure that the data are complete and accurate and, also, that all the statistical assumptions required of the summary analyses can be verified. The typical user of the data system may never see the basic data, but rather will rely on the integrity of the data handlers to provide him with accurate information. The importance of this trust is emphasized. If the data summaries do not use valid statistical techniques or do not take into consideration any relevant properties of the data, then the user may reach incorrect and possibly costly conclusions.

Data summaries represent very simple types of data retrievals. The following is an example of a data summary and possible conclusions to be drawn from such a summary:

> After detailed data collection and storage of data for an industrial plant, evaluation of the data first is done, usually based on a summary of the quantities of the air pollutants separately being emitted from the total plant or from the different facilities. This summary then may show relevant critical emissions concerning pollutants or their quantity. Action then should be taken to reduce the quantity of a special pollutant, if present only at a single or only very few facilities. If the summary does not allow such a conclusion directly, further evaluations (data retrievals) must be made.

4.3 Data Flow Systems

The handling of emissions inventory data involves various levels of administration and possibly private organizations.

The responsibility for gathering and maintaining the emissions inventory rests with the government agency. In some cases, this responsibility may be delegated to local agencies. The systems in use by the NATO countries vary only slightly.

4.3.1 Flow of Information into the System

Regardless of which agency has the responsibility, the first step after establishing an emissions inventory system is to gather inventory data. The original data are obtained from questionnaires (e.g., existing industrial plants) or a permit system (e.g., new plants) and are updated through the same mechanism or by inspections. The next step is to estimate, calculate, or verify emissions data.

Once data are entered into the system they are submitted to other interested government agencies (e.g., the local authorities in the Netherlands).

In general, the input into the emissions inventory data bank involves several different agencies such as the firms responsible for emissions (polluters), licensing authorities, independent expert agencies, lower administrative bodies, and government agencies.

Further information on data flow, control and updating is outlined in national papers in the Appendix.

4.3.2 Flow of Results from the System

Once the data are in the emissions inventory system, they are accessible to the personnel responsible for the data. Government agencies or local agencies, such as licensing bodies, can request data or summaries. The aspect of confidentiality is mentioned in most national papers. The use of confidential data in most emissions inventory systems is limited to aggregated statistics only; individual information is available outside the emissions inventory only with approval of the submitter.

Status reports and management reports as well as certain publications may be generated periodically. However, the publications may contain summary information only because of confidentiality reasons.

5. Check List for Establishing an Emissions Inventory System

In the foregoing sections and in the technical papers (see the NATO/CCMS Doc. No. 104), a great deal of the experience obtained by the participating countries in developing and operating emissions inventory systems has been presented. A number of suggestions have evolved from this background, as outlined below.

5.1 Planning an Emissions Inventory

When planning an emissions inventory, three major issues should be addressed: (1) the objectives of the inventory, (2) the geographical area that the inventory will cover and, (3) the emitter categories to be included.

There are several objectives of an emissions inventory system. They may include (1) the planning and directing of improvements in a high pollution area and (2) the planning of new industrial facilities, highways, residential areas, etc. In all cases, the level of detail (resolution) required for the desired objectives should be considered along with the instruments available to carry them through.

The geographical area to be considered may be an entire continent, a country or its major areas, or only certain urbanized areas. In defining the source categories that will be taken into account, the planner should carefully consider which categories are to be included. After designation of the source categories, a decision should be made whether to cover sources of all sizes or only the major ones. For each case a different level of detail will be required, thus influencing the character of the inventory.

5.2 Designing an Emissions Inventory System

After consideration of the objectives of the system, the availability of data, and the funds available for data collection and handling, three issues should be addressed in designing an emissions inventory system: (1) elements covered by the inventory, (2) the required level of detail (resolution) of the elements and, (3) the required relationship of the emissions inventory system with other data systems.

Certain elements are common in the systems of all participating countries. These are:

- emitter identification
- activity and equipment
- source data
- control equipment and efficiency
- emissions data (amount, pollutant, location and time).

5.3 Collection of Data

For successful collection of data, the following suggestions are recommended:

1) Establish good cooperation with sources of information (e.g., industry, local authories).

2) Ensure confidentiality of data.

3) Minimize the burden on the respondents.

4) Perform representative source testing whenever feasible.

5) Provide ease of computerization.

Suggestions (1) through (3) are meant to provide optimal access to available data, thus ensuring optimal quality of the collected data. The burden on the respondents can be greatly reduced if they are not required to fill out the data forms. A more efficient procedure which results in data of better quality is one in which the respondents just collect available data, while the forms are filled out by specially trained emissions inventory personnel.

5.4 Data Handling

The following suggestions are offered on data handling:

1) Determine the need of computerization according to the volume of data to be collected and the required frequency and type of data retrieval.

2) Identify specific summaries and retrievals associated with the objectives of the emissions inventory system.

3) Allow for adequate growth of the data files.

Suggestions (1) and (2) are meant to ensure that the results will address the original objectives of the inventory system. Data which do not satisfy the stated requirements can cause problems for any data system.

5.5 Updating the Emissions Inventory

In most cases, the regular updating of the data system is desirable. To ensure that the system is updated, a reporting system should be established. This could be done by regular reporting (e.g., on a yearly basis) or reporting only when modifications greater than a certain extent occur.

Updating also could be combined with the procedure of granting new operating permits for installations on which major modifications have been made. Whether size modifications should be reported depends on their effect on the sum of the emissions of the pollutant in the area.

5.6 Revising the Emissions Inventory System

A regular evaluation of a data system is needed to ensure that the system still meets the original objectives and/or new objectives. If the system is no longer in accordance with the objectives, the necessary modifications should be made. This may result in the elimination of the system elements that are no longer needed.

Appendix B Air Pollution Emissions Projecting

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1. Introduction

This appendix is concerned with alternative emission projection techniques and describes the relationship of emissions projecting to the Air Quality Management System (AQM). Based on the experience of several NATO countries, principles are given for applying the projecting techniques to the available emissions inventory data bases and to the other data required. This appendix is identical with NATO/CCMS Doc. No. 100 on Air Pollution Emissions Projecting, which also includes two further appendices.

2. General

2.1 Alternative Methods of Estimating Future Emissions

Projecting future levels of emissions involves a wide range of possible activities. The simpliest procedure involves the application of generalized growth factors to current production or emission levels for general sources categories, whereas comprehensive emission projecting requires regional demographic projections, detailed land use growth factors, and quantitative methodologies to depict the complicated interrelationships between industrial categories. Past and present emissions can also be used independently (via statistical techniques) to project future emission trends. This method, however, is not generally appropriate and has proved inadequate for both planning purposes and for focusing attention on likely problem areas.

Emission forecasts, both in principle and practice, involve the future estimates of two independent parameters: activity rates and the net emissions associated with each unit of those activity rates. Population, production rates, and energy consumption are examples of activity rates that must be estimated by the forecaster for the selected geographical area. These activity rates are then transformed into anticipated emissions via "controlled" emission factors+) which are the quantities of emissions actually discharged for each unit of activity. This parameter includes the probable, future-like pollution control efficiency and changing technology for each source category. The projected activity rate is multiplied by this value to obtain the total emissions. For example, a 30 % increase in total cement production might be anticipated between 1975 and 1985. Through knowledge of current and impending pollution control legislation and an estimate of the relative mix of wet and dry cement kilns in 1985, the forecaster determines the controlled emission factor (e. g., the net emission rate per unit of cement production). These two items are multiplied together to yield the total emissions from cement manufacturing that are expected in 1985.

It should be emphasized that some countries (e. g., FR Germany) define emission factors as the net release of atmospheric emissions whereas others (e. g., U.S.) utilize the concept of uncontrolled emission factors. In the latter case, controlled emissions are calculated by separately including the effect of the expected control efficiency. Both approaches are entirely suitable for purposes of emission inventories and emission projections.

+) Emission inventorying techniques normally use uncontrolled emission factors whereby the existing control efficiencies are separately applied for each individual source. In projecting, however, the major influence on emissions is the degree of expected and enforceable performance standards. These are generally written as maximum emissions allowed per unit of activity or process throughput. For this reason it is easier and more logical to compile a future, "controlled" emission factor to multiply against an industrial category's future activity level.

2.2 Responsibilities in Forecasting

As discussed later in this paper, in-depth forecasting first requires a detailed and accurate emissions inventory for the geographical areas of interest. Thus comprehensive emissions forecasting is usually undertaken by mature air pollution control agencies with an established grasp of their local problems. Moreover, there is a direct need for interdepartmental data (i. e., expected traffic growth and land use patterns); for this reason accurate forecasting is usually accomplished at a lower level of administrative control, (e. g., those agencies responsible for one to two million population). In this manner, the probable changes and patterns in emission levels are immediately available for investigating alternative control strategies to solve the local problems.

Emissions forecasting must also be conducted at the national level because nationwide decisions are continually being made on a day-to-day basis. Responsibilities of the national program are threefold; to provide a uniform set of procedures, formats and guidelines for local agencies to use in forecasting emissions; to transmit projections to the local agencies on the expected effects of national and regional control programs (e. g., future emission factors for automobiles); and to maintain a back-up or default forecasting system in the event that local agencies are not sucessful in their forecasting efforts. It is also important to recognize that demographic, economic, and industrial growth data are often collected on a routine basis by centralized nationwide agencies. Such information can often be obtained directly from these agencies in a machine-readable format. This makes the information ideal for incorporation directly into the forecasting system and for transmittal to the appropriate local agencies for their use.

2.3 Relationship to the AQMS

Within the framework of an overall air quality management system, detailed forecasting methodologies are needed only after assessment has been truly accomplished (and an up-to-date emissions inventory is available). At this rather mature stage of program development, emission forecasts not only provide future estimates based upon today's strategies, but also is an ideal mechanism for comparing effects of various control strategies. Thus, emission forecasting is a vital management tool and has an integral role in the planning and evaluation activities of control agencies.

2.4 Uncertainties of Forecasts

Successful forecasting depends as little as possible upon historical patterns and emission trends. Rather, it relies heavily on externalized predictors of population, industrial growth, life styles, effects of current control strategies, and probable technological developments. Uncertainties in these factors invariably introduce errors into the forecasts and may be extremely difficult to quantify. Statistical confidence in these input parameters improves as the forecasting time period decreases and is likely to be fairly accurate for up to three to five years. Fortunately, this is generally adequate for evaluating pollution control strategies and for taking any corrective management action.

3. Uses of Emission Forecasts

3.1 Macro-Forecasting

The macro-forecasting concept is generally useful only for large, homogeneous geographical areas. Summary emission statistics for generalized source categories are usually obtained through the macro-fore-casting technique; these statistics are then used primarily in decisions associated with the total air management system. Emission estimates are calculated as a first approximation having moderate precision and used in overall management decisions involving reallocation of resources within the general air quality management system. They are also useful in evaluating long-range strategies involving the development and application of "what if?" scenarios.

One advantage of macro-forecasting is the usual availability of activity growth parameters from established branches of the national government that deal routinely with demographic, economic, and energy data. Such references are often also used in calculating emissions for the current emissions inventory and thus their projections are also applicable for the emission forecasting effort. It should be recognized, however, that adjustment and assumptions must sooner or later be made in transforming economic or energy parameters to emission projections. For example, national forecasts for future sales of coal may be assumed to be equivalent to coal consumption and used accordingly in emission projections. Such assumptions are necessary, yet all must clearly be detailed in the methodology so that the forecasts can routinely be updated as new data become available. This updating capability is especially important when the original emission forecasts are compared with the actual emissions inventory and appropriate adjustments made to the second generation of forecasts. The capability of such adjustments allows the AQMS to apply forecasts with assurance that they are correct and to adjust priorities accordingly. Utilizing these forecasts, the AQMS can periodically reallocate resources to those programs having the largest emission-reduction potentials.

3.2 Micro-Forecasting

Emission forecasting of very small geographical areas or even individual sources has been found to be valuable in plant siting studies, local land-use planning, and in preparing environmental impact statements for highway construction and other public works projects. In determining the impact of contemplated projects, the micro-forecasting techniques invariably yields higher precision data than the macro-forecasting method. Obviously, however, this techniques is more expensive to implement and is most applicable to short-range, local forecasting. Results of micro-forecasts in conjunction with the detailed source inventory provide details that are readily used as data for direct input air pollution dispersion models.

Usually micro-scale forecasting is more effectively conducted or evaluated by the local pollution control agency. This is true because local topography, meteorology, zoning regulations, and other regional considerations are highly important variables in micro-forecasting. Also, emission projections and expected impact on air quality are part of environmental impact statements and permit applications. For this reason, standard formats, calculation procedures, and outputs should be formulated by the local agency as soon as possible, preferably before micro-forecasting becomes an implied part of their reporting requirements. Due to the high costs of micro-forecasting, this activity is probably limited to established pollution agencies representing 2 - 3 million inhabitants.

4. Needed Data and Capabilities

4.1 Baseline Emissions Inventory

Emissions inventories are generally composed of three categories of emitters: point, line and area. In the most detailed inventories, a large fraction of the emission total is represented by the point/line source data base. Thus the comprehensive inventory contains many data items for a large number of individual emitters. Some countries, such as the Netherlands, incorporate forecasting data on individual facilities directly into their baseline emissions inventory. Until such sophistication is reached, however, most emissions are likely to be determined by the area source data base whereby individual emitters are represented by a relatively few, aggregated categories.

Many data items for a few sources is one characteristic of micro-forecasting due to the small geographical area involved and the high accuracies expected. Impact of current emission laws must be determined for each source and incorporated into the baseline inventory, preferably as a function of equivalent control efficiencies. Future activity rates are obtained from the sources themselves via surveys or in conjunction with routine enforcement/testing efforts. Thus, while the current source inventory may include a large number of data items regarding a particular source, only three additional items are needed to forecast emissions from that source: the future year, the operating rate for that year, and the expected equivalent control efficiency. This concept is also easily applied to area source categories such as mobile sources and residential fuel consumption. For such sources, equivalent control efficiency may actually represent the fuel-mix or low-sulfur regulations whereby the activity rate indicates a composite growth parameter such as total residential fuel demand.

The above discussion assumes that extensive work has been done in obtaining correct data for the current inventory and that all major sources are included in the data base. This is especially important in micro-forecasting small geographical areas where the absence of only a few sources in the current inventory can lead to large errors in forecasts. The importance of all point sources being represented in the inventory decreases significantly as the geographical area of interest becomes larger. In the transition from micro to macro-forecasting, incompleteness in the point source inventory is often corrected automatically by adjustments to the area source inventory. In the U.S.A. this self-correction occurs through the initial use of aggregated activity rates and subsequent apportioning to point and area source contributions. For example, in the U.S.A. the total, national consumption of coal is known through routine publications: the total coal consumed by all point sources in the emission inventory is calculated and automatically subtracted to yield the coal contribution from area sources.

Macro-forecasting utilizes an aggregated emissions inventory that is intrinsically free from local variations in activity rates (e. g., traffic patterns) that dramatically affect the micro-forecasting of local areas. Automobile usage, for example, is easily obtained nationally and inherently more accurate than for a city or other small area.

4.2 Other Data Needs

Successful forecasting requires the collection and use of data other than the baseline emissions inventory. Many of these exogenous inputs are also used, directly, or indirectly, to calculate and apportion emissions in the current data base; and the identical algorithms can also be applied to the forecasting methodology. There are five basic categories of information utilized in emissions forecasting. These data must all be filtered past the question: "What is the realistic estimate (the anticipated situation) as opposed to what is hoped will occur (the proposed situations)?"

Census and Economic Information:

Anticipated demographic and industrial growth rates are vitally necessary to forecasting and, fortunately, are generally easy to acquire from the national government. These references are commonly used to compile the current inventory and therefore conversion procedures are already established for use in the forecasting efforts.

Effects of Existing and Proposed Regulations:

Including the effects of pollution regulations is best incorporated into the emission forecasts by using equivalent control efficiencies and projected activity growth rates for given source categories. The most stringent emission limitations should be applied (local, regional, or national), however caution is advised to differentiate between a proposed timetable for compliance compared with the probale percentage of sources that will meet the law in a given year. People are usually overly optimistic and believe that existing laws will take effect much more quickly than actually occurs. This is particularly true in estimating the impact and time schedule of proposed regulations and it is adviseable to be especially conservative in this area. The true relationships between time spans and emission reductions may be successfully reduced from historical legislation and previous emissions inventories.

Control Technology:

Process changes and emissions control technology are often difficult to estimate but must be considered, especially for new facilities yet to be constructed. Emission reductions are most cheaply achieved by implementing performance regulations for new sources rather than by extensive controls on existing sources of pollution. For this reason, the established air quality management system will eventually consider legislation requiring best available control technology to be utilized by new facilities. The effects of developing technology of new source performance standards are gradual and may not be significant when short-term emission forecasts are compiled.

Emission Factors:

Emission factors relate emissions of a specific source category (without emission controls) to an operating rate. The concept and use of emission factors is absolutely necessary in compiling a comprehensive baseline inventory and is also essential in macro-forecasting where measured emission data are not available. Controlled emission factors can also be developed for processes to be constructed at some future time (e. g., coal liquification) for use in forecasting emissions.

Local Data:

The fifth and last category of forecasting data encompasses land use zoning, transportation control strategies, and alternative siting locations for new plants. These considerations are strictly local in nature and applicable only for microforecasting. The influence of such factors depends entirely on lateral coordination within local governmental bodies such as between the pollution control agency and the regional planning commission. Employing these factors to modify air pollution levels and patterns in the community requires a highly developed, integrated program that can be achieved only after a long period of time and effort.

4.3 Form and Content of Forecasts

To facilitate comparison, it is preferable that forecasted emissions are in exactly the same format as the current emissions inventory and that they both have the same detailed and summary capabilities. Whether manual or automatic reporting is used, the same analysis capabilities must be available to both current and forecasted emissions. In fact, micro and macro results may both be required for modeling the predicted pollutant concentrations. Thus both the macro-scale (summary statistics) and the micro-scale (detailed source statistics) data are utilized in good air pollution control management.

Time scales of micro and macro data requirements must also be considered in forecasting emissions. Usually, summary statistics are presented as annual emissions and forecasted emissions must be compatible and over the same time duration. In addition to these requirements, micro-scale statistics must predict seasonal fuel use, industrial production, and transportation statistics to facilitate interpolation to hourly emission rates needed for atmospheric dispersion modeling. The forecasting system must also be able to predict emissions for all pollutants in the current existing emissions inventory for each comparison with the current data.

4.4 Validation of Forecasting Methodologies

Continual review and revision of the selected forecasting system is highly desirable and can be accomplished in a number of ways. One meachanism is to compare the previously forecasted emissions with the actual outcome shown by the emissions inventory. For this to occur, the forecasting system must be operational for at least two years. If it is seen that major deviations (± 30 %) exist between the predicted and actual emissions, this usually indicates that improper growth factors are being applied to some emission categories and that revisions are needed. For example, anticipated population forecasts may be used in the forecasting system to estimate changes in emissions of organic solvents. Validation of the system may reveal that growth in hardware retail sales (e. g., paint) is a more appropriate growth parameter than population data. Of course, values for these new parameters must always be realistically available and the forecasting system must be suitably flexible to accommodate such substitutions.

Another means of validating and correcting the forecasting system is to devise parallel forecasting systems for comparative purposes. This is generally done by comparing emission projections of different organizations for their own purposes. For example, the regional pollution control agency might use local traffic/planning data to forecast emissions which can easily be compared with predictions from the nationwide forecasting system to evaluate differences and subsequently reconcile these variations.

5. Resource Considerations

The resources required to forecast emissions depend entirely upon the priority and importance placed on the results by the AQMS. Once the methodology is developed and procedures standardized, a macro-forecast at the national level will require little time and effort. In the U.S.A. such results are utilized in national trends documents and to indicate expected progress of the national air management program. Micro-forecasting, however, might require much more time to complete for each regional area. It is therefore generally advisable to encourage different levels of effort in micro-forecasting so that the first "rough" forecasts can direct the area of emphasis in the subsequent, more sophisticated micro-forecasts.

There are three functional areas associated with micro-forecasting that are especially resource intensive. The first, improvement of the current emissions inventory, is generally necessary because many errors or gaps will become evident upon close scruting. The second, obtaining projected activity rates and equivalent efficiencies for individual point sources, can effectively be accomplished only via door-to-door surveys of the emitters. The third resource - intensive activity is the acquisition of local planning and transportation information and the subsequent synthesis of such data into tabulation of expected growth rates.

Appendix C Introduction to Air Quality Modeling+)

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+) This appendix is identical to the main part of NATO/CCMS Doc. No. 99 on the same topic.

1. Aims and goals of Air Quality Modeling (AQM)

The goal of AQ Modeling is to supply pertinent information for decisions made within the framework of AQ Management Systems, especially in connection with control strategies. The fundamental problem which has to be solved within an AQM is to calculate air concentrations of one or more species in space and time as related to the independent variables such as the emissions into the atmosphere, the meteorological variables, and such parameters which describe removal and transformation processes. All these independent variables can be functions of space and time, but need not all be considered. If these air concentration fields are calculated as functions of space and time one can obtain from them hourly, daily, monthly or yearly averages or frequency distributions of concentrations at a given point in the field, which in most cases will be at the surface. This aim is achieved by a system, which relates quantitatively the concentrations to the other parameters by mathematical and/or physical methods. Such a procedure is called a "model".

It is very important to note here that the type of information which is needed for the decisions in the AQMS determines to a large extent what type of model is to be used. But not only the type of information which is used from the output of a model determines model type and sophistication but also the type and

The purpose of this introduction is not to give a detailed review of the existing models but to review the methods used for modeling, in particular for models to be used in AQMS, in order to give indications where they could preferably be applied, to state their advantages and disadvantages and summarize the problems connected with the application of models.

2. Air Quality Models (AQMs)

General Remarks

The principal subdivision which is made in this text is that between deterministic, statistical and physical models. According to this subdivision a deterministic model is one which calculates the concentrations from an emission inventory and other independent, mostly meteorological variables according to the solution of various equations that represent the relevant physical processes. In contrast to the deterministic model the statistical one calculates concentrations by statistical methods from meteorological and other parameters after the statistical relationship has been obtained empirically from measured concentrations. An emission inventory is not needed. The physical model is a model, in which nature is simulated on a smaller scale in the laboratory, e. g. in a windtunnel.

The deterministic model is most suitable for long term planing decisions. The statistical model is very useful for short term forecasts of concentrations and the physical model may then be of use, if only influences of topography or high buildings in the surroundings of large sources have to be considered. Unfortunately, the last model type is seldom employed to give quantitative results in the above sense and is therefore rarely used in AQ Modeling.

2.1 Deterministic Models

Most of the deterministic models use or are equivalent to using solutions of the diffusion equation. The diffusion equation is based on the principle of conservation of mass. The turbulent fluxes of material are expressed by the gradient relationship, i. e. it is assumed that the turbulent flux is proportional to the gradient of concentration and the proportionality "constant" is called the diffusion coefficient. The diffusion equation reads as follows:

$$\frac{\partial \bar{s}}{\partial t} + \bar{u}\frac{\partial \bar{s}}{\partial x} + \bar{v}\frac{\partial \bar{s}}{\partial y} + w\frac{\partial \bar{s}}{\partial z} = \frac{\partial}{\partial x}\left(k_x \frac{\partial \bar{s}}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial \bar{s}}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial \bar{s}}{\partial z}\right) \qquad (1)$$

+ source terms + transformation terms.

The symbols have the following meaning:

$\bar{s}$ = the time averaged concentration

x,y,z = the cartesian coordinates

$\bar{u},\bar{v},\bar{w}$ = the components of the time averaged wind vector

k_x,k_y,k_z = the diffusion coefficents in the corresponding directions.

If the earth's surface is horizontal and no buoyancy effects are taken into account, the vertical component of the time averaged wind vector is zero and the last term on the left hand side of (1) vanishes. Furthermore, if diffusion is only considered in the lowest, approximately 100 meters of the atmosphere, wind direction does not change with height and the coordinate system can be directed with its x-axis into the direction of the flow. From that it follows that $\bar{v}$ = 0 and the third term of the left hand side of (1) vanishes. For wind velocities greater than ca. 1 m/sec, the following inequality holds

$$\bar{u} \frac{\partial \bar{s}}{\partial x} \gg \frac{\partial}{\partial x}\left(k_x \frac{\partial s}{\partial x}\right) \qquad (2)$$

and the first term of the right hand side of (1) is neglected according to (2).

Apart from the problems connected with the solution of the (parabolic) partial differential equation the main problem is to obtain the meteorological parameters of (1), i. e. the wind vector and the diffusion coefficients, which are in general functions of space and time. The wind vector can be measured by methods well known (although to get these measurements as function of space and time in a required density involves large efforts). The greater problem is to state the diffusion coefficients, since they cannot be measured directly. In fact, they can only be determined a posteriori, i. e. from simultaneous flux- and gradient-measurements, and are then applied for situations, where one assumes that the flow characteristics are the same as in the case where measurements were made.

The boundary conditions at the earth's surface have to be stated and it is often assumed that the diffusing material (gases) is not absorbed by the ground, i. e. the material is "reflected" into the atmosphere. The other extreme case, that all material reaching the surface is absorbed, is not appropriate at least for gases and very seldom used. Partial reflection of the material at the ground is the most realistic case but it involves the statement of another parameter, which is usually called the deposition velocity, and only recently have reliable values been obtained by experiments.

Often a boundary condition for the upper boundary of the diffusion volume is stated, especially in case of an inversion. In that case too the total reflection assumption at the upper boundary is used.

The models calculate the concentration at one receptor point from one source. If more than one source is present then the contributions from each source at the receptor point are summed. Only for the simplest assumptions of the meteorological parameters analytical solutions of the diffusion equation exist. For a realistic modeling it is therefore unavoidable to solve the diffusion equation numerically.

2.1.1 Steady State Models

The steady state condition implies that all variables and parameters are constant in time. This includes the concentration, i. e. $\frac{\partial s}{\partial t} = 0$. However, steady state solutions are often obtained with the time dependent equation ($\frac{\partial s}{\partial t} \neq 0$), but with all meteorological and other parameters kept constant. One then calculates forward in time until the steady state is reached for the concentration. Therefore, the models mentioned under 2.1.2 can also be used for steady state modeling. Steady state models - by the nature of the inherent assumptions of the time constancy of the parameters - can be applied only for shorter distances (order of 10 km) and of shorter travel times (order of 2 hours).

2.1.1.1 The Gaussian Model

The most widely used model in AQMS is the Gaussian Model, which is a steady state model. The term Gaussian Model originates from the fact, that the vertical and horizontal (perpendicular to the mean wind direction) concentration distributions are Gaussian normal distributions, the standard deviations `$_y$ and `$_z$ of which are functions of source distance and the meteorological situation. These `-values and -functions have been obtained by diffusion experiments in the atmosphere and are related through so-called diffusion categorys schemes (for example that of Pasquill's) to easily measured meteorological (surface) parameters. Although there is still some discrepancy about the way to find the best set of `-values for a particular problem, this model is widely used, because it is rather simple and easy to handle.

The Gaussian concentration formula for a plume is an analytical solution of the simplified diffusion equation in case of a continuous point source

$$\bar{u} \frac{\partial \bar{s}}{\partial x} = k_z \frac{\partial^2 \bar{s}}{\partial z^2} + k_y \frac{\partial^2 \bar{s}}{\partial y^2} \qquad (3)$$

with the relation

$$\sigma_i^2 = 2 k_i \frac{x}{\bar{u}} \qquad i = y, z \qquad (4)$$

Besides the assumption that $\bar{u}$, k_z and k_y are constants (also with height) it is usually assumed that the material is reflected at the earths surface. Area sources are often simulated by a larger number of point sources distributed equally over the source area. Solutions for an infinite and a finite line source exist also.

In order to comply with the assumption inherent in the model that $\bar{u}$ = const. in most models a vertically averaged wind profile is introduced.

2.1.1.2 Other Models

As mentioned before all time dependent models under 2.1.2 can be used as steady state models.

2.1.1.3 Simple Model

One extremely simple model for the calculation of concentrations from area sources ("ATDL-Model") has been given, where the concentration is proportional to the source strength and inversely proportional to the mean wind speed. The proportionality constant depends on stability, mixing height and city size. But even with an average proportionality constant empirically obtained the model gives satisfactory results.

2.1.2 Time-dependent Models

In a time dependent model all variables can be functions of time and the concentration is calculated depending on time. With a relatively few exceptions all time dependent models go back in principle to a solution of the diffusion equation (1), but formulations and solution methods differ. The box models and the grid models are the models most widely used.

2.1.2.1 Box Models

In a box model the atmosphere is divided into a number of boxes of given length, width and height. In each of the boxes the concentration is assumed to be constant. For each box a budget equation is solved for each time step taking into account the fluxes of material across the boundaries of the boxes (advective and turbulent), sources, sinks, sedimentation, deposition, transformation etc. Such a box model is graphic, easy to formulate and relatively easy to handle.

2.1.2.2 Grid Models

The grid model solves the diffusion equation after it has been transformed into a finite difference equation in Eulerian space. The concentration values are obtained at the grid points and are averages in time and space according to the chosen time step and grid size.

The large number of existing grid models differ with respect to

1. resolution in time and space
2. formulation of the finite differences
3. treatment of sources and sinks
4. treatment of and assumptions on meteorological parameters
5. division into horizontal and vertical diffusion
6. methods to avoid numerical diffusion
7. inclusion of chemical reactions and transformations.

Grid models and also box models are mostly used for the simulation of episodes, because the computational effort connected with their application is large. In fact it is so large that the computation of, say, hourly values for an extensive time period like a year or more is very time consuring. Usually simulation times greater than a few days cannot be afforded. A combination of grid- or box models on one hand and statistical models on the other seems a promising way of studying emission and meteorological effects seperately or for long term planning, if a measuring network exists.

2.1.2.3 Spectral Models

The spectral models differ from those under 2.1.2.2 in that the diffusion eqation is transformed into Fourier space and then solved. The advantage here is that one avoids numerical truncation errors. There does not seem to be an advantage in computational effort.

2.1.2.4 Lagrangian and Random Walk Models

In a Lagrangian model individual air parcels are followed and the concentration computed for each parcel. Numerical diffusion is avoided, but the disadvantage is that very large computer storage and time is needed. The same is true for random walk models, where particles perform a random walk in grid space with prescribed transition probabilities. Because of the computer economics involved both models do not seem to be applicable when frequency statistics of concentrations are needed.

2.1.2.5 Trajectory Model

The trajectory model is a special type of Lagrangian model, where the trajectory of the center of gravity of a diffusing cloud is computed first and then the diffusion with respect to this center of gravity is taken into account. Again, large computational effort is required for a multiple source model. It seems however to be applicable for short term forecasts in connection with dangerous, unintentional releases of material, e. g. in the case of an accident.

2.2 Statistical models

Statistical models as defined before relate measured concentrations at one point or from a measuring network to simultaneously measured variables, such as meteorological parameters, time of day or year, etc. The so obtained statistical relationship is used for forecasting the concentrations for a given set of the above variables. The emission characteristics, however, must not change between the time of measurements and the application time, i. e. no additional sources can be added or the existing sources can not change their time-dependent behaviour. The advantage of such models is their small computational effort and that they simulate measured concentrations (see 2.2.1) fields or concentration (see 2.2.2). No emission inventory is needed. The disadvantage besides the one already mentioned is that concentration measurements are needed. They seem especially suitable for short term forecasts in an area where concentration values are measured. They can also be used to take into account background concentrations in a deterministic model.

2.2.1 Regression Model

This simple model relates measured concentrations at one point to meteorological variables. It has not been used widely, since its usefulness is very limited.

2.2.2 Empirical Orthogonal Functions

In this model measured concentration values at a number of stations are related by statistical methods to pertinent meteorological variables and time. The mathematical method employed uses Eigenvector and -coefficients for the concentration correlation matrix. This method is relatively simple and fast.

2.3 Physical Models

As already mentioned under 2. the physical model will simulate nature on a smaller scale, i. e. in the laboratory in a wind - or water tunnel. It is in general, not used in AQ modeling with the exception of studies of influences of topography and high buildings in the surroundings of large sources.

3. Problems connected with AQ Modeling

3.1 Time and Space Averaging

Numerical models average the concentration values in space and time according to the time step and grid spacing or box size employed in the model. The measurements on the other hand give also time averaged, but mostly not space averaged concentrations. The calculated and measured concentrations are then not immediately comparable. This will be especially pronounced in areas with steep concentration gradients. It is therefore a problem how to compare these two values. Furthermore, grid spacing or box sizes must be in accordance with the grid size of the emission inventory. It is therefore not sensible, to calculate concentrations in a grid that is smaller than that of the emission inventory. Large single sources have often to be treated in a special way.

3.2 Input Data

There are many problems connected with any type of input data. It is often advisable to perform sensitivity analysis with a model in order to study the influence of each input parameter on the results. From this analysis one can determine or estimate which input parameters have to be known to which degree of precision.

3.2.1 Emission Data

Usually the emission data are not detailed enough in space and time. This is because a large effort is necessary to compile an emission inventory even with its simplest characteristics. Especially the changes of the source behaviour as function of time are not known in detail. One is also forced to treat the large number of small sources - for example those from domestic heating or from automobiles - in a simplifying manner, that one assumes area sources for the domestic heating or line sources for automobiles. These simplifying assumptions introduce error possibilities.

3.2.2 Meteorological Data

Again, the meteorological data will in many cases not be dense enough in space and time to supply to a model the input parameters in a satisfying manner. Mostly, only surface values of the meteorological parameters are available and the turbulence characteristics in the boundary layer of the atmosphere must be estimated from surface data. Even if vertical profiles of temparature and wind are measured at one or several places the time intervals between measurements are a few to several hours and the values in between have to be estimated. Another problem is how to determine from the vertical profiles the diffusion coefficients needed in the model. To sum up it is very seldom that enough meteorological data are available for application of AQMs on a climatological basis, i. e. to compute hourly concentration values 24 hours a day throughout a whole year.

3.2.3 Plume Rise

The height of the emission of material is very important for the surface concentration values. In many cases this height is not identical with the height of release because the plume rises due to density differences to its surroundings and momentum excess. There exist a large number of formulae which try to describe the plume behaviour, but they differ considerably in their results and it is still controversial which formula is "the best". The plume rise value is rather sensitive to the temperature stratification in the boundary layer and measurements of vertical temperature profiles are not always available.

3.3 Representation of Results

There is no standard way in which the results of a AQM are presented. Preferably two dimensional concentration fields in the way of isolines of mean values, 95 percentiles, etc. should be given. Also frequency distributions or cumulative frequency distributions of concentrations at a given location are helpful.

3.4 Calibration of Models

The idea which is behind this terminology is to compare model results with measured concentrations and that one can obtain one or several empirical factors which bring calculated and measured values in agreement. Usually this does not work because the results depend on so many parameters that it is not possible to determine one or even several factors which improve the results under all circumstances. In addition, even if there is such a factor or factors which have been determined from past measurements these factors might not be correct for the future.

3.5 Verification of Models

The quantitative description of model performance presents problems. Correlation coefficients averaged in space or time describe only a linear relationship. Mean ratios of calculated to observed concentrations can distort the picture. The same is true for the standard error of estimate, because there is a large variation of orders of magnitude in the concentrations values. The suggestion which is made here is that as many as possible of the statistical performance measures should be given.

3.6 Transformation and Removal Processes

For large distances (greater than ca. 10 km) or large travel times (more than few hours) transformation and removal processes become important. In a few cases (automobile exhausts) even for very small travel times the transformation process has to be considered. Apart from the fact that deterministic modeling becomes more and more difficult when these processes are included - the computational effort will increase considerably - there are not enough data on rate coefficients and their behaviour in the atmosphere. Therefore, the modeling of the mentioned type of processes is still in its beginning and research work is strongly needed.

3.7 Topographic influences

The topography and orography in the area where AQM is applied influence strongly the meteorological parameters and through them the concentration field. Typical examples are sea breeze and mountain effects. A combination of mesoscale meteorological models with AQM can give insight in the magnitude of these effects. This type of study is still in the research stage. But since large computer storages and times are required for those calculations it is not foreseen that AQMS can rely in the near future on this type of combined modeling.

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